Measurement method for urine puddle depth in dairy cow houses as input variable for ammonia emission modelling

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Abstract: Dairy cow houses are a major contributor to ammonia (NH_3) emission in many European countries. To understand and predict NH_3 emissions from cubicle dairy cow houses a mechanistic model was developed and a sensitivity analysis was performed to assess the contribution to NH3 emission of each input variable related to a single urine puddle. Results showed that NH3 emission was most sensitive for five puddle-related input variables: pH, depth, initial urea concentration, area and temperature. Unfortunately, cow house data of these variables are scarce due to a lack of proper measurement methods. In this study we focused on a method to assess the urine puddle depth, which can vary between 0.10 mm and 2.00 mm.

Our objective was to develop a measurement method for the urine puddle depth capable of assessing this variable on the floor in commercial dairy cow houses with a measurement uncertainty of at least 0.1 mm. In this study we compared two measurement methods being the balance method as golden standard and the ultrasonic method to use in practical dairy cow houses. We measured water puddles in an experimental setup under various conditions.

We concluded that the ultrasonic sensor, attached to an X-Y table, can measure puddle depth and can determine depth differences between puddles both with a measurement uncertainty of 0.1 mm. The comparison between the balance and the ultrasonic method gave a mean difference of <0.01 mm (se = 0.006) in puddle depth; a Tukey mean-difference plot showed that the two methods were proportional and that there was no systematic bias.

Keywords: cow urine, puddle depth, ammonia emission, the Netherlands

Citation: Snoek, D. J.W. 2015. Measurement method for urine puddle depth in dairy cow houses as input variable for ammonia emission modelling. Agric Eng Int: CIGR Journal, Special issue 2015: 18th World Congress of CIGR: 30-36

1 Introduction

Ammonia (NH_3) emission can cause environmental pollution, is a precursor of fine dust particles and is an indirect source of nitrous oxide. To lower NH_3 emission a National Emission Ceiling (NEC) is set for each EU member states. The 2010 NEC set by the European Commission was met by twenty-five of the 27 EU member states, including the Netherlands. Further mitigation of NH_3 emission will be necessary in the EU, since the expected NECs set for 2020 will be lower than the NEC 2010. In 2010, 94% of all NH_3 emission from the 27 EU member states originated from agriculture. Of this, livestock production systems were responsible for 80%. In the Netherlands, in a typical dairy cow house consisting of a living area with cubicles, slatted floor plus walking and feeding-alleys and a slurry pit underneath the whole house, about 70% of its NH_3 emission emits from the floor.

To understand and predict NH_3 emissions from a dairy cow house a mechanistic model was developed (Monteny et al., 1998) and a sensitivity analysis was performed to assess the contribution to NH_3 emission of each input variable related to a single urine puddle (Snoek et al.,

Received date: 2014-10-28 Accepted date: 2014-11-28
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2012, 2014). They concluded that NH_3 emission was most sensitive for five puddle-related input variables: pH, depth, initial urea concentration, area and temperature. However, cow house data of these variables are scarce due to a lack of proper measurement methods. In this study we focussed on a method to assess the urine puddle depth, which can vary between 0.10 mm and 2.00 mm.

Two methods for quantification of puddle depth have been used in earlier research (Aamink & Elzing, 1998). First, in an experimental setup a measured 0.5 kg of urine was poured over an area of 10 *10 cm clean and fouled slatted floors and the surplus was collected and weighted. Second, the same amount of urine was poured over a clean solid floor area and the wetted area was determined. In both cases the mean depth was the volume divided by the area. Depth values were reported with a resolution of 0.01 mm. It was noted that the depth on the solid floor might have been too shallow since they only used clean floors and that depth has a significant effect on ammonia emission.

Another option is to use a laser relief meter to measure distance (Zhixiong et al., 2005). We tested this meter within this study and we concluded that this meter cannot be used to measure urine puddles, since the laser was not able to measure distance to a liquid.

Our objective was to develop a measurement method for the urine puddle depth capable of assessing this variable on the floor in commercial dairy cow houses with a measurement uncertainty of at least 0.1 mm. In this study we explored measurement principles and we performed a preliminary experiment.

2 Materials and methods

In this study we conducted experiments to compare two measurement methods to determine puddle depth, being the balance method (§0) as golden standard and the ultrasonic method (§0) to use in practical dairy cow houses.

2.1 Balance method

The urine puddle depth was measured in an experimental setup to use as reference. A collection tray (internal dimensions: 500 mm * 305 mm * 25 mm) was put on the floor. This tray was filled and emptied with water step by step with a cup. The cup was weighted with a balance (Mettler balance, max. 60 kg type KB60, error=0.01 kg) before and after each step that water was poured in or taken out the tray. The amount of water varied for each step. The depth was the volume (calculated from weight / specific weight) divided by the area. A depth of 0.1 mm was equal to 0.015 kg of water and 0.001 kg water was less than 0.01 mm depth.

2.2 Ultrasonic method

The urine puddle depth was measured with an ultrasonic device that can measure distance with an accuracy and display resolution of 0.1 mm and an internal resolution of 0.01 mm. Puddle depth was determined by subtracting the distance to the puddle from the distance to the floor without puddle. To measure puddle depth at various locations of a urine puddle, we measured the distance to the puddle at various locations and at exactly the same locations after puddle removal. To do this we operated an X-Y table (Figure 1). The ultrasonic was attached to this table and we could move it 35 cm in X and 60 cm in Y direction. The distance between the ultrasonic and the floor was 5 cm. To remove a puddle we used a Kärcher® Window Vac WV 50 to vacuum up the puddle from the floor.

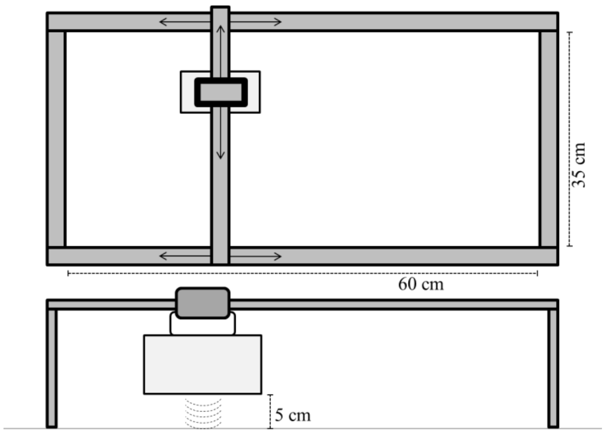

Figure 1 Schematic representation of the top and side view of the X-Y table with the ultrasonic device and sound waves

2.3 Validate accuracy ultrasonic method

Table 1Conducted experiments with a brief description and the used measurement methods

Experiment	Brief description	Methods
1	Ultrasonic at fixed position in centre of collection tray (Figure 2)	Balance and ultrasonic
2	Ultrasonic at 4 locations in collection tray (Figure 2)	Balance and ultrasonic
3	Ultrasonic at 9 locations at floor element (Figure 3)	Only ultrasonic
4	Ultrasonic at 9 locations at floor element (Figure 3)	Only ultrasonic

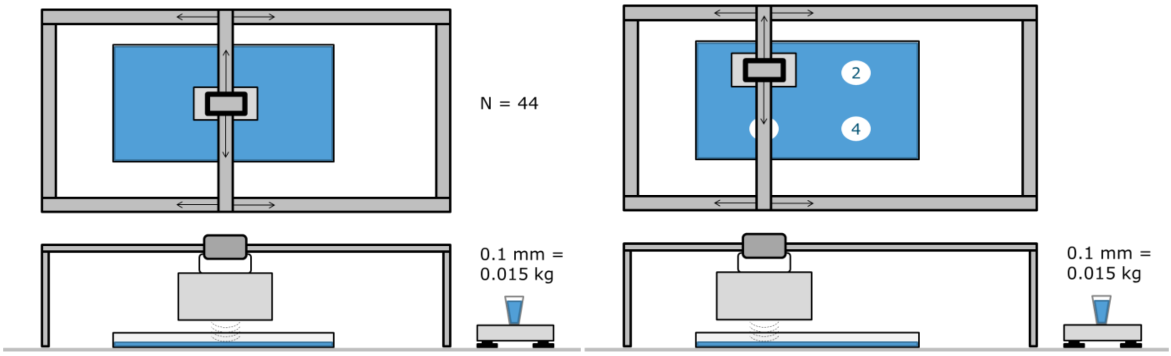

Figure 2 Schematic representation of experiment 1 (left), the ultrasonic in the centre of the collection tray of the four locations in the collection tray; and experiment 2 (right), the ultrasonic and the four location in the collection tray

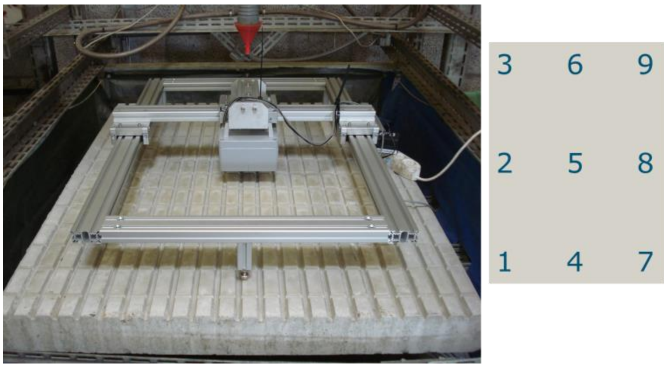

Figure 3 Schematic representation (right) of the nine locations at the floor element (left)

Table 1 shows an overview of the conducted experiments. Puddle depth values were measured both with the balance (reference) and ultrasonic method at the same time in the experimental setup with collection tray (experiment 1 and 2). In experiment 3 and 4 only the ultrasonic device was used at an experimental setup with the welfare floor 2 (Snoek et al., 2010). In experiments 2, 3 and 4 distance measured with the ultrasonic device was done before, during, and after removal of the puddle. Puddle depth (pd) was determined by subtracting 'distance before' from 'distance to puddle' (pd1) and by subtracting 'distance after removal' from 'distance to puddle' (pd2).

2.3.1 Experiment 1

The ultrasonic was positioned above the centre of the empty collection tray. We gently poured water in and took water out, spread over two measurement series and in varying order. The distance measured with the ultrasonic was saved each time the water level was stable again. For each consecutive step we calculated the increase in depth of the water level determined by both the balance and the ultrasonic method. To assess agreement between the two methods we made a Tukey mean-difference plot, also called Bland-Altman plot (Bland & Altman, 2010). Except for five steps we tried to keep the added or removed amount of water small to generate depth changes around 0.1 mm. The five steps with a larger amount elevated the water level in the tray to cover a wider measurement range.

2.3.2 Experiment 2

The collection tray was filled with about 1 kg of water to be sure to have a levelled base. Four locations were defined (错误!未找到引用源。). The ultrasonic was positioned at location 1 of 4. Then the ultrasonic was moved in a sequence consisting of three times a fixed order, being location 1-2-3-4, and three times in a random order. We measured each location according to the sequence before, during, and after puddle removal and pd1_tray and pd2_tray were determined (§0). We executed a one sample t-test to check the difference between mean depth by the ultrasonic with the single depth measure by the balance method, and we executed an independent samples t-test for equality of means between fixed and random order movement within pd1_tray and pd2_tray. We did not test for equality of means between pd1_tray and pd2_tray since the amount of water poured in differed from the amount of water taken out.

2.3.3 Experiment 3

The X-Y table with the ultrasonic was put on the welfare floor 2 in our experimental setup (Snoek, 2010). Nine locations were defined (错误!未找到引用源。), excluding gutter area. The ultrasonic was positioned at location 1 of 9. Then the ultrasonic was moved in a sequence consisting of a fixed order, being location 1-2-3-4-5-6-7-8-9, a random order, and again in fixed and random order for another four times. In total each location was measured 10 times of which five in fixed movement order and five in random order. In this experiment it was not possible to use the balance method. We measured each location according to the sequence before, during, and after puddle removal and pd1_floor and pd2_floor were determined (§0).We executed an independent samples t-test for equality of means between fixed and random order movement within pd1_floor and pd2_floor, and a paired samples t-test for equality of means between pd1_floor and pd2_floor.

2.3.4 Experiment 4

Copy of §0, but this time locations 1 to 9 were measured only twice to determine pd1_floor and pd2_floor, first by fixed and second by random movement order. Location 1 was measured a second time as number 10 in each series. We repeated this for 3 puddles. We executed an anova to test for differences between the three puddles within pd1_floor and pd2_floor, and a paired samples t-test for equality of means between pd1_floor and pd2_floor.

3 Results

3.1 Experiment 1

错误!未找到引用源。 shows the Tukey mean-difference plot. Mean difference was <0.01 mm, with SD = 0.05, SE = 0.006, and 95% limits of agreements of mean difference ± 1.96 SD being -0.09 mm to 0.10 mm. Besides, the 95% confidence interval for the bias was -0.01 to 0.01 mm. Regression analysis resulted in R^2 = 0.0012 (P=0.78), slope = 0.0024 (P=0.78) and intercept = 0.0013 (P=0.83). So the two methods were proportional to each other with no systematic bias.

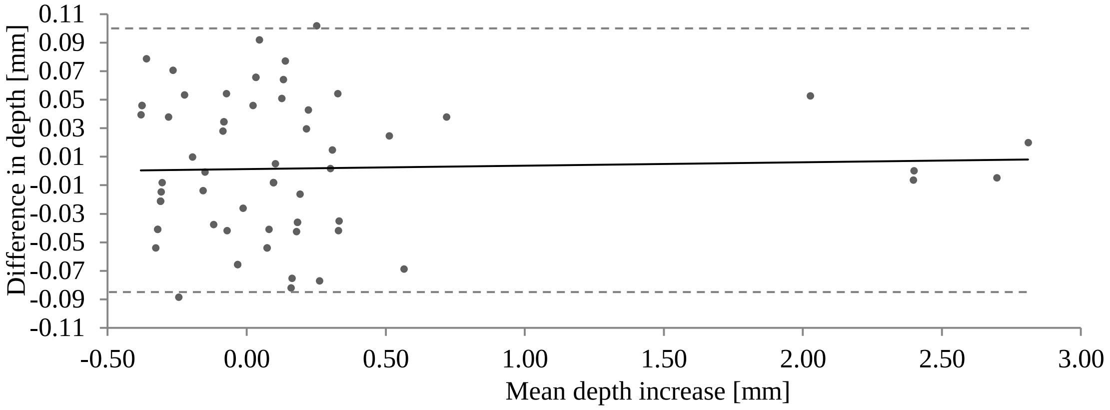

Figure 4 Tukey mean-difference plot with 95% limits of agreement. Difference in depth [mm] between the balance and ultrasonic method plotted against mean depth increase [mm] of both methods. R2 = 0.0012 (P=0.78), slope = 0.0024 (P=0.78), intercept = 0.0013 (P=0.83). Mean ±1.96 SD (_ _)

3.2 Experiment 2

Table 2 shows mean depth for pd1_tray and pd2_tray with ultrasonic movement in fixed and random order, and the differences. For pd1_tray the mean difference between fixed and random order was <0.01 mm and for pd2_tray -0.01 mm, and in both cases this difference was not significant (>0.10). Difference between the mean depth by the ultrasonic and the depth by the balance method did not differ significantly (>0.05).

Table 2 N, mean depth (mm) and SE for pd1_tray and pd2_tray, for fixed and random movement by the ultrasonic, and the depth by the balance method. Followed by the independent samples t-test for equality of means of fixed vs random movement

	pd1_tray		pd2_tray	
Movement order	Fixed	Random	Fixed	Random
N	12	12	12	12
Mean depth in mm (SE)	0.10 (0.02)	0.10 (0.01)	0.18 (0.03)	0.18 (0.02)
Depth in mm (balance method)[a]	0.10		0.15	
Mean difference in mm (p-value)	<0.01 (1.000)		-0.01 (0.784)	

Note: [a] Mean depth of ultrasonic and depth by balance method did not differ significantly (>0.05)

3.3 Experiment 3

Table 3 shows mean depth for pd1_floor and pd2_floor with ultrasonic movement in fixed and random order, and the differences. First, for both pd1_floor and pd2_floor the mean difference between fixed and random order was 0.01 mm and in both cases this difference was not significant (>0.10). Second, the mean difference between pd1_floor and pd2_floor was 0.08 mm and this difference was significant (<0.05). The mean time it took to measure one location was 12 s (SE=0.3).

Table 3 N, mean depth (mm) and SE for pd1_floor and pd2_floor for fixed and random movement by the ultrasonic. Followed by the independent samples t-test for equality of means of fixed vs random and the paired samples t-test for equality of means of pd1_floor vs pd2_floor

		pd1_floor		pd2_floor	
	Movement order	Fixed	Random	Fixed	Random
Descriptives	N	45	45	45	45
	Mean depth in mm (SE)	0.72 (0.05)	0.71 (0.04)	0.64 (0.04)	0.63 (0.05)
Independent t-test	Mean difference in mm	0.01 (0.888)		0.01 (0.890)	
Paired t-test	Mean depth in mm (SE)	0.71 (0.03)		0.64 (0.03)	
	Mean difference in mm	0.08 0.000)			

3.4 Experiment 4

Table **4** shows mean depth for pd1_floor and pd2_floor for 3 puddles, and the differences. First, for both pd1_floor and pd2_floor the mean differences between the puddles did not differ significantly (each comparison >0.10). Second, the mean difference between pd1_floor and pd2_floor was <0.01 mm and this difference was not significant (>0.10). The mean time it took to measure one location was 11 s (SE=0.4).

Table 4 N, mean depth (mm) and SE for pd1 and pd2_floor for puddles 1-3 by the ultrasonic. Followed by the one-way anova for equality of means between the puddles (homogeneous subsets), and the paired samples t-test for equality of means of pd1_floor vs pd2_floor

	pd1_floor			pd2_floor		
Puddle	1	2	3	1	2	3
N	20	10[a]	20	20	20	20
Mean depth in mm (SE)	0.68	0.65	0.71	0.68	0.66	0.70
Homogeneoussubsets[b]	1	1	1	1	1	1
Mean depth in mm (SE)		0.68 (0.03)			0.68 (0.03)	
Mean difference in mm			<0.01 (1.000)[c]			

Note: [a] Missed one series of 10 measurements.

[b] Subset 1 of pd1_floor was not the same as subset 1 of pd2_floor.

[c] Same series of 10 measurements excluded from pd2_floor, to be equal to pd1_floor, so N = 50 for both.

4 Discussion

The Tukey mean-difference plot shows that both the balance and the ultrasonic method were proportional with no systematic bias and with low SD and SE. We assumed the balance method as golden standard, so the ultrasonic sensor, attached to the X-Y table, can measure puddle depth with a measurement uncertainty of 0.1 mm.

The readability of the ultrasonic was 0.1 mm. So values like the depth of 0.15 mm by the balance method (Table **2**) may be a problem for the ultrasonic. In this example, with N = 24, the difference between the mean depth by the ultrasonic and the depth by the balance method was not significant, so no systematic deviation. And in each conducted experiment in this study the SE was small that means that there was a good estimate of the mean. So we conclude that the ultrasonic sensor, attached to the X-Y table, can determine depth differences among puddles with an accuracy of 0.1 mm.

The distance between the ultrasonic and the floor, attached to the X-Y table, was set at about 5 cm. This distance can slightly be adjusted by changing the length of the legs of the table. In general the distance have to be as small as possible, since the distance measurement is based on sound waves and is thus sensitive for temperature changes and air movement. To correct for this the ultrasonic contains a temperature sensor. We conducted a preliminary experiment by changing the height of the ultrasonic to a fixed, solid, plate from 25.0 mm to 80.0 mm with steps of 1.0 mm, with a calliper as reference. It turned out that the measured distance with the ultrasonic was correct for the whole range, but at larger distances the sensor becomes more sensitive for changing air temperature and air movement compared to smaller distances. Based on this preliminary experiment, and the results in this paper, we conclude that 5 cm distance is feasible. A shorter distance is better, but then we will get practical problems in case there is solid manure on the floor, for example.

Measurements with the balance underneath the collection tray may be more accurate. But in preliminary test experiments it turned out that the balance was pressed by the weight of the water, resulting in unknown changing distances towards the ultrasonic device. Because of this the tray was put on the concrete floor.

By adding or removing water, the added water or the cup ruffled the surface of the water in the collection tray. We waited until the water was visually stable and the ultrasonic distance measurement gave a stable result.

5 Conclusions

First we concluded that the ultrasonic sensor, attached to the X-Y table, can measure puddle depth and can determine depth differences between puddles both with a measurement uncertainty of 0.1 mm. The comparison between the balance and the ultrasonic method gave a mean difference of <0.01 mm (se=0.006) in puddle depth; the Tukey mean-difference plot shows that the two methods were proportional and that there was no systematic bias; and the difference between the ultrasonic and balance method in the movement test above the collection tray was not significant.

Second we concluded that there is no significant difference (>0.10) in the depth measurement by moving the ultrasonic in a fixed or random movement order along the axis of the X-Y table.

Third we concluded that evaporation did not influence the measurement. Measurements at the welfare floor 2 (§0) show low SE values, while the measurement period was long (20 min). The time it took to move to and measure one location was 12 s, so a series of 10 locations takes about 2 min. We expect no significant depth change by evaporation in this short period of time.

Finally we concluded that the method to remove a puddle worked well in the experimental setup.

5.1 Recommendations and follow up

The measurement uncertainty of 0.1 mm is necessary and sufficient to enable comparison of floor systems and to generate urine puddle depth values for NH_3 modelling purposes. Based on the results of this study, the ultrasonic method will be used to measure urine puddle depths in commercial dairy cow houses. Therefore, we will test the puddle removal method in a commercial dairy cow house and we will determine the exact measurement procedure. Then we select floor types, find dairy farmers and design the experiment. Finally we will measure puddle depth values in commercial dairy cow houses.

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