Engineering Note: EN0077 Moisture Control Methods for Batching Systems

Summary:	Outlines methods for moisture control in batching systems
Products affected:	All Products
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1 Summary

This engineering note explains moisture control methods for batching systems. A batching system usually consists of a number of raw material silos or hoppers and a mixer combining these materials to create a final product.

This engineering note uses the International system of units throughout. It also assumes the specific gravity of water is 1. It does not account for changes in specific gravity of water at different temperatures as this change is negligible.

2 Silos and hoppers

Formulations or recipes are most commonly specified by the dry weight of a material. In practice it is quite common for materials to contain moisture. This affects the weight of the material and its bulk density. This change in bulk density is due to either the particles themselves expanding, for example seed grains or the material changing its surface tension, for example sand clumping together at certain moisture contents.

2.1 Batching by volume

The change in volume due to moisture is difficult to measure, it is often non-linear and correlating the correct adjustment to make based on the moisture is therefore very difficult to achieve. Hydronix recommends that volumetric systems should be replaced by weigh systems.

2.2 Batching by weight

The change in weight due to moisture is a linear change. Whilst it is true that the specific gravity of water does change with temperature, to all practical intents and purposes, it can be treated as a constant of 1. This helps simplify the control process as 1L of water can be considered to be 1kg.

Example:

Material weight 1,000kg

Moisture Content = 10%

1,000 x 0.1 = 100kg water

Specific gravity of water @ 0°C (ref temp 20°C) = 1.002

100kg / 1.002 = 99.8L

Specific gravity of water @ 37.8°C (ref temp 20°C) = 0.995

100kg / 0.995 = 100.5L

This change is less than the achievable accuracy of an industrial weight batching system and so the remainder of this note will assume a specific gravity for water of 1. It will also assume that all material data will be referenced against this assumption.

In order for weight batching systems to weigh material accurately in a time efficient manner it is necessary to dose a large proportion of the material first, known as the main dose, weigh the material that has been dosed and then add the remaining requirement of material more slowly through a series of fine doses. A fine dose is the opening of the gate for a small period of time and allowing a small amount of material to pass through it and then closing the gate. The material is weighed after each fine dose until the demanded amount of material is added.

Moisture control can be integrated in to this process without any cost to overall batching time. The final weight target can be adjusted prior to fine dosing. This depends on the expected moisture variation in the material. The main dose should be set to less than the moisture range of the material. As weighing at this point is less accurate it is sensible to add a 5% tolerance on the value to account for any overshoot or undershoot of the target.

Example:

Driest expected moisture = 3%

Wettest expected moisture = 18%

Tolerance = 5%

Moisture Range = 18 – 3 = 15%

Main Dose = 100 – 15 – 5 = 80%

During the main dose it is important to average the moisture measurements of the sensor. The moisture will vary over the course of the batch and compensation should be based on the overall moisture and not on any single reading at the end of the batch.

Averaging should be done using the Averaging/Hold function provided by Hydronix sensors. This eliminates any errors that can occur from reading sensor outputs over the analogue loop, outputs such as noise on the cable or the resolution of an analogue card input.

The averaging in the sensor can be used either by energizing the digital input to the sensor or via the RS485 connection.

After the main dose the averaged value is held, and can be obtained from the sensor and the final weight target can be adjusted. To calculate the actual weight of material that needs to be weighed the following formula should be applied:

$$T = T_d(100\% + M\%)$$

Figure 1: Wet Weight Calculation

Where:

T = Total Weight of material to add

T_d = Dry weight of material required for batch

M = Moisture of material (NB: 100% = 1, M% = Moisture/100)

Example:

Target Dry weight of material = 1,000kg

Main dose = 80%

Main dose target = 1,000 x 0.8 = 800kg

Actual main dose weight = 780kg (allowing for some weigh error)

Average Moisture = 10%

Final Target = 1,000 x (100%+10%) = 1,000 x (1 + 0.1) = 1,100 kg

2.2.1 Control Processes

For systems where the hopper/silo will only ever hold one material it is recommended that the calibration be held in the sensor and the output of the sensor set to give average moisture. For systems that may hold several materials at different times it is recommended that the output for the sensor should be set to average Unscaled. The calibration must then be done in the control system.

Pseudo Code for hopper/silo batching process where the sensor is configured to output moisture.

1. Set the main dose target to a percentage of the final target that allows for overshoot plus moisture variation (Note: in the example above this was 80%).
2. Open Hopper/Silo gate.
3. Start averaging in the sensor either by energizing the digital input or sending start averaging command via RS485.
4. While the weigh scale is less than target, keep gate open until the target is reached.
5. Stop Averaging either by de-energizing the digital input or sending stop averaging command via RS485.
6. Close Hopper/Silo Gate.
7. Take the average moisture reading from the sensor and calculate the final target weight using the equation in figure 1.
8. While the weigh scale is less than the final target, open and close gate for short periods (fine dosing) until the final target is within acceptable tolerance.

For systems that must hold multiple calibrations it is necessary to calculate the moisture from the Unscaled value. This is simple as the response from the sensor to moisture addition is linear.

$$Moisture\ \% = B.Unscaled + C - D$$

Figure 2: Moisture Calculation from Unscaled value

Where:

B = Unscaled change per Moisture% change (gradient)

C = Offset (theoretical Unscaled value when moisture = 0)

D = Adsorption value

Note: the D value is only required if free moisture is to be displayed rather than total moisture otherwise it can be set to 0.

2.2.2 Material Calibration

During Material calibration, the moisture content of the material and the Unscaled value at that moisture should be collected for several points preferably across the entire working range of the material. The working range of the material is between the lowest possible moisture of the material during production and the highest. It is recommended to have at least 3 points over the working range. Hydronix sensors cannot be used to measure moistures below the water adsorption value of a material and so it is recommended to keep materials above this value.

Example:

A sand has a water adsorption value of 1.5%, it is saturated at 16%.

In production the sand will be kept above 2% and adds too much water to the process above 8%.

The working range is therefore 2-8%.

Samples should be collected for the sand at approximately 2, 5 and 8%.

To calculate the B and C values from multiple points, whilst there are many methods, using linear least squares regression is perhaps the most common. It is the method that Hydronix recommends.

$$B = \frac{\sum Moisuture\ Values.UnscaledValues - \left(\frac{\sum Moisture\ Values\ .\sum Unscaled\ Values}{Number\ of\ points}\right)}{\sum Unscaled\ Values^2 - \left(\frac{\sum Unscaled\ Values\ .\sum Unscaled\ Values}{Number\ of\ points}\right)}$$

Figure 3: Calculation of B value

$$C = \frac{\sum Moisture\ Values - B.\sum Unscaled\ Values}{Number\ of\ points}$$

Figure 4: Calculation of C value

Example

Unscaled	Moisture
20	2
30	5
40	8

*B = (((20*2)+(30*5)+(40*8))–((2+5+8).(20+30+40)/3)) / ((202+302+402) - ((20+30+40).(20+30+40)/3)))*

*B = (510 – (15 * 90 / 3)) / ((400+900+1600) – (90 * 90/3)*

B = 60 / (2900 – 2700)

B = 60 / 200

B = 0.3

*C = ((2+5+8) – 0.3 * (20+30+40)) / 3*

C = (15 – 27) / 3

C = -4

3 Mixers

Moisture control in mixers usually consists of adding water up to a target value. This can be done using either a calculation method or a trickle feed method. A calculation method involves measuring the material moisture and then calculating the amount of water to add in one dose.

The calculation method requires accurate material dry weights.

The trickle feed method is more resilient to inaccurate dry weights but is slower than the calculation method.

The trickle feed method requires a consistent water pressure to be available.

This document covers the control processes involved in each method. For more explanation on the usage of each method refer to Chapters 4 and 5 of HD0456, the Hydro-Control VI Operators Guide.

In HD0456 the calculation mode is referred to as “CALC” mode. The trickle feed method is referred to as “AUTO” mode.

It is important to note that mixing, unlike hoppers and silos which usually hold a single material at any one time, involves blending materials together.

A blend of materials can be considered to be one material as long as the constituent materials remain in the same proportions and are allowed enough time to mix together becoming homogenous. A blend of materials is commonly called a recipe or formulation depending on the industry type. They are essentially the same thing.

A mixing cycle will consist of:

1. Adding materials
2. Blending materials together until a stable signal is achieved
3. Adding water
4. Blending the materials and the water until a stable signal is achieved
5. Discharging of the material

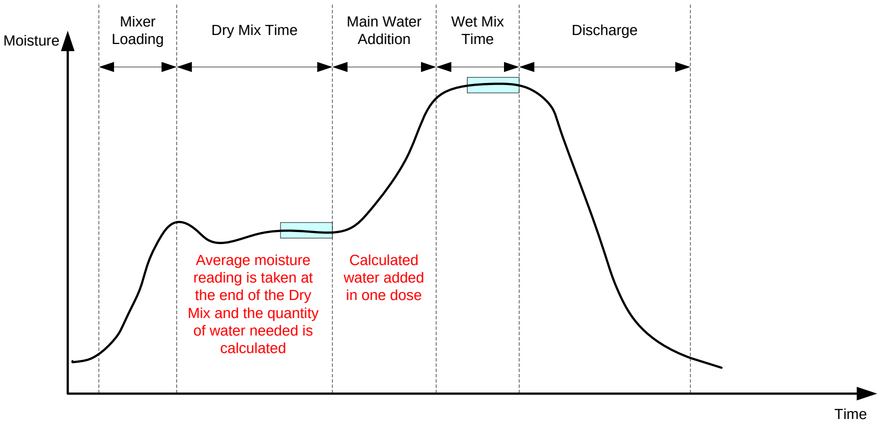

Figure 5 - Mix cycle

There may be a requirement to repeat steps 2-4 if different materials need to be added at different stages or if adding materials (such as metals) cause an adverse effect on the sensor signal.

3.1 Implementing the calculation method

To calculate how much water to add the Unscaled value from the sensor should be used. In order to make the calculation it is necessary to allow the operator to use a manual method where a predetermined amount of water can be added based on the recipe design and the operators knowledge of the moisture content of incoming materials. This will allow the operator to create a reference mix. Figure 6 shows the process of the reference mix

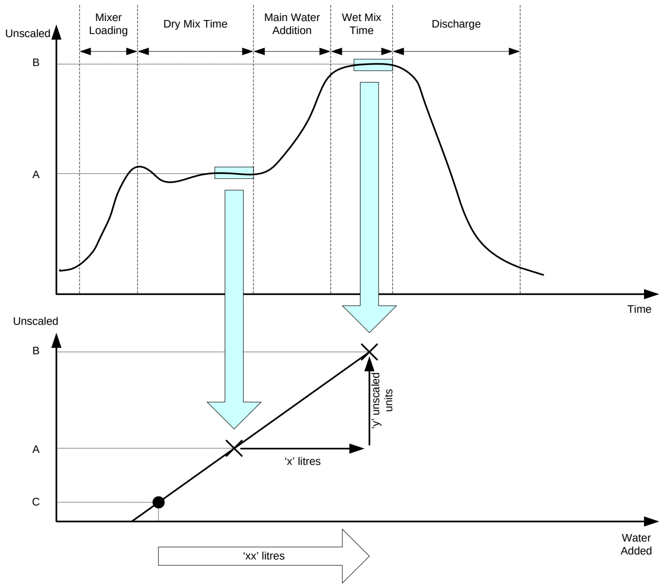

Figure 6: The calibration points from the mix cycle

A stable measurement is obtained at the end of the dry mix time and at the end of the wet mix time. It is recommended that the signal from the sensor be averaged for at least five seconds.

The Unscaled change per unit of moisture increase (the gradient of the graph) can be calculated as shown in figure 7.

$$B = \frac{100.Water}{Dry\ weight\left(Unscaled_{wet} - Unscaled_{dry}\right)}$$

N.B: the value 100 is a scaling factor to allow the B value to be used in the equation of figure 2

Figure 7: Calculation of the water addition gradient

It should be noted that the dry weight is the total dry weight of all materials added excluding the water and any moisture already in the incoming material.

In the recipe the wet mix value and the B value should be recorded for use during production. To calculate how much water to add to a dry recipe or formulation the equation in figure 8 can be used.

$$Water\ Required = \frac{Dry\ weight\ .B.\left(Unscaled_{target} -\ Unscaled_{current}\right)}{100}$$

Note: the value 100 is a scaling factor to allow the B value to be used in the equation of figure 2

Figure 8: Calculating the required water during a mix

To calculate a moisture value it is necessary to apply an offset. Calculating an offset requires the user to state the final moisture value. This can be obtained either by lab testing the finished product or if this is not possible (such as in concrete production where a chemical reaction starts converting water in to another substance) the moisture content can be calculated using figure 9.

$$\%Final\ Moisture = \frac{100(Water\ in\ raw\ materials + Water\ added\ during\ mix)}{Total\ Dry\ weight\ of\ materials}$$

Figure 9: Calculating final moisture of product

To convert the Unscaled value of the sensor to moisture content for display purposes an offset must be calculated as shown in figure 10.

$$C = Moisture_{target} - Unscaled_{target}.B$$

Figure 10: Calculating the offset for the calibration

It is then possible to display moisture using the equation in figure 2.

3.2 Implementing the trickle feed method

The most effective form of trickle feed method involves altering the water flow rate so that at the start of the water addition the flow rate is high and as the moisture level of the recipe gets closer to the target moisture the flow rate is reduced so as not to overshoot the target. The most common way to do this is by implementing a Proportional Integral Derivative Controller (PID Controller). Most PLC systems have PID Controllers as built in function blocks.

For a fuller explanation of a PID controller see HD0456 Chapter 8 section 3.3.

If the mixer system has a proportional valve attached this is relatively simple to do. The system should store a Proportional gain value, an integral gain value and a derivative gain value. As mixing systems cannot recover from an overshoot (too much water) the derivative value should be set to 0.

The Control Output for the proportional valve can then be worked out using the following equation.

$$\mathrm{u}(t) = \mathrm{MV}(t) = K_p e(t) + K_i \int_0^t e(\tau)\,d\tau + K_d \frac{d}{dt} e(t)$$

where

K_p: Proportional gain, a tuning parameter

K_i: Integral gain, a tuning parameter

K_d: Derivative gain, a tuning parameter

e: Error = Target Value (Unscaled) – Current value (Unscaled)

t: Time or instantaneous time (the present)

τ: Variable of integration; takes on values from time 0 to the present t.

MV(*t*) = Manipulated variable (or Control Output). This is limited to 0-100 in the case of a valve.

Essentially the proportional part is a simple ratio of error therefore the larger the error, the larger the response. The Integral part is the sum of error over time. The longer an error exists, the larger the response to the error. The derivative part is the rate of change of error. If the rate of change in the error is high then the effect of the derivative control is greater. This is most keenly noticed during overshoot where the rate of change of error accelerates in the wrong direction thus reducing the aggressiveness of the loop.

Example

Target = 50 Unscaled
Proportional gain, $K_p = 5$
Integral gain, $K_i = 0.1$
Derivative gain, $K_d = 0$

@ Time, t = 0
Current Unscaled = 30

MV(t) = 5(50-30) + 1(50-30) + 0(50-30)
MV(t) = 100 + 2 + 0
MV(t) = 102

>MV(t) limit therefore Control Output(C.O) = 100

@t=1
Current Unscaled = 40

MV(t) = 5(50- 40) + 0.1(50- 40) + 0.1(50-30) + 0(50-40)
MV(t) = 50 + 1 + 2 + 0
MV(t) = 53
C.O = 53

@t=2
Current Unscaled = 45 (reduction in increase as C.O is < 100 now)

MV(t) = 5(50-45) + 0.1(50-45) + 0.1(50- 40) + 0.1(50-30) + 0(50-48)
MV(t) = 25 + 0.5 + 1 + 2 + 0
MV(t) = 28.5
C.O = 28.5

@t=3
Current Unscaled = 50
MV(t) = 5(50-50) + 0.1(50-50) + 0.1(50-45) + 1(50-40) + 0.1(50-30) + 0(50-50)
MV(t) = 0 + 0 + .5 + 1 + 2 + 0
C.O = 3.5

At this point the target has been reached and the valve can be switched off. If no integral gain had been used the valve would have been shut off more as the current value approached the target thus slowing the increase significantly. This leads to longer water addition times but is less likely to cause overshoot. In processes where some water is lost the longer the mixing takes this integral gain will increase the aggressiveness of the loop as time progresses to effectively eliminate the offset caused by losses.

As most mixer systems cannot afford to overshoot additions it is necessary to introduce a dead band region. This is usually an offset from the true target to prevent overshooting. For example if the target was 5% moisture an offset of 0.2% could be introduced to stop the controller at 4.8%. This compensates for the time between water being added and the time it takes for the water to mix in and be measured by the sensor.

In the case of systems that have only digital valves rather than proportional valves it is necessary to imitate a proportional valve as best as possible. A simple method of doing this is shown in the example below

Example

1. *Define a cycle period such as the time it takes to switch a valve from off to on and then back to the off position*
2. *Define a control period, for example this could be 5 cycle periods.*
3. *After each control period calculate MV(t).*
4. *80 < MV(t) <= 100 = Valve stays on for 5 cycle periods*

    60 < MV(t) < 80 = Valve stays on for 4 cycle periods and off for 1 cycle period

    40 < MV(t) < 60 = Valve stays on for 3 cycle periods and off for 2 cycle periods

    20 < MV(t) < 40 = Valve stays on for 2 cycle periods and off for 3 cycle periods

    0 < MV(t) < 20 = Valve stays on for 1 cycle period and off for 4 cycle periods

As with all PID controllers some experimentation is required to obtain values that achieve optimum performance for the mixing system.