Consistency Control: Systematic and Scientific Design leads to Many Different Strategies

Jack Tippett, Emerson Process Management

ABSTRACT

Consistency control is one of the most important and yet common controls in the wet end of a paper machine. Nevertheless, it is at the same time one of the most poorly implemented loops on many paper machines.

In this presentation, the several different process objectives with appropriate control strategies will be considered. These strategies take into consideration varying production demand, varying dilution line pressure, limited measurement capabilities and varying stock properties.

What will be shown is that although there is no single ideal strategy, that at times the simple two element strategy is best, but, at other times, that dilution flow ratio, proportional only dilution flow, recirculation or adaptive gain controls are better choices.

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INTRODUCTION

The control of consistency is a very large topic to cover well in a short paper. Our focus will be from the perspective of process control, specifically looking at the strategies that one can use to perform low variability consistency control.

The EnTech Control Performance Group of Emerson Process Management encourages a scientific and methodical approach to process and control design, control tuning and process troubleshooting.

In taking that approach, this paper will address the following:
- What are the Process Objectives and constraints for the most common consistency processes?
- What are the potential impediments to achieving those objectives?
- What are the Control Strategy Objectives that will help to achieve the Process Objectives?
- For the most common forms of consistency processes, what are the most appropriate strategies?

Like physicists, many control engineers would like to find one strategy that will solve all control problems (The Unified Field Theory for control engineering). Unlike Physicists, Control Engineers are expected to be practical. So the key thesis of this paper is that there is no single strategy for consistency control that satisfies all requirements. However, using a scientific and methodical approach to the problem, one can make significant improvements to the various consistency processes in a mill by choosing the most appropriate strategies for them.

PROCESS OBJECTIVES

Before the control strategy for a process can be designed, one must first consider the process objectives. This is true for any process (not just consistency control), but is often not addressed in the development of the strategy or the design of the process.

One might state that the objective of any consistency process is to deliver stock downstream (the demand flow) at a uniform consistency under all circumstances. While this may be ideal, the blind implementation of this objective in all consistency loops may be impractical and unnecessarily expensive.

There are primarily five differing process objectives for consistency control found around the paper mill. These are:

1   Small Consistency cut, constant demand:
This is normally done by adjusting a dilution water valve based on feedback from a consistency transmitter in the demand flow (downstream) line. The consistency from the feed chest to the demand flow line is reduced by a small amount (typically a cut of 0.5% to 1 % consistency producing stock in 3 – 5 % consistency range). The demand is virtually constant (varying only by 20-30%). This is one of the most common forms of the consistency process, usually found in Machine Chest or Blend Chest Consistency controls.

2   Small Consistency cut, wide demand
This is similar to the previous form, except that the demand changes greatly (varying with a turndown of 3:1 and up to 10:1). This form of the consistency process may be found in LD (Low Density) chests for specialty fibres such as OCC, that must support widely varying demand based on varying fibres percentages required on a given grade (from 5% to 100% of the blended stock).

3   Large Consistency cut, constant demand
This is normally implemented by a dual dilution system. A trim dilution water valve is adjusted based on feedback from a consistency transmitter in the demand flow (downstream) line and at the same time a much larger water flow (called the zone dilution or tower dilution) is controlled into the chest, resulting in a large change of consistency (a cut of 6-10 % consistency, with a feed stock of 12 – 16 % consistency range and the downstream stock of 4-6 %consistency). The demand is virtually constant (varying only by 20-30%). This is found at the HD (High Density) tanks of the main fibre type supplying the paper machine and employing dual dilution (a zone or tower dilution flow and a trim flow).

4   Large Consistency cut, wide demand
This is similar to the previous form, except that the demand changes greatly (varying with a turndown of 3:1 and up to 10:1). This is found at the HD tanks of specialty fibre type (supplying the LD chest in form 2), and employing dual dilution (a zone or tower dilution flow and a trim flow).

**5   Consistency blending, feed forward control**
This uses feed forward calculations based on the consistency and flows of merging components (usually requiring large cut in the consistency). It most commonly would be found in the Thick Stock / Lean Stock mixing process but may also be found in strategies for maintaining the feed consistency at a Saveall. This form of control, while very important is not the key focus of this talk. .

Note that in most feedback cases, the consistency control can be quite satisfactory even if the transmitter is not calibrated properly. In the case of stock blending applications however, this is not so as the process objective is to provide demand flow of a known (not just constant) proportion of each ingredient.

OPPORTUNITIES FOR PROBLEMS

In order to understand some of the problems that may be impediments to achieving the process objectives, consider the following schematic. Note that the problems fall into three main categories: transmitters, actuators and tuning and external disturbances.
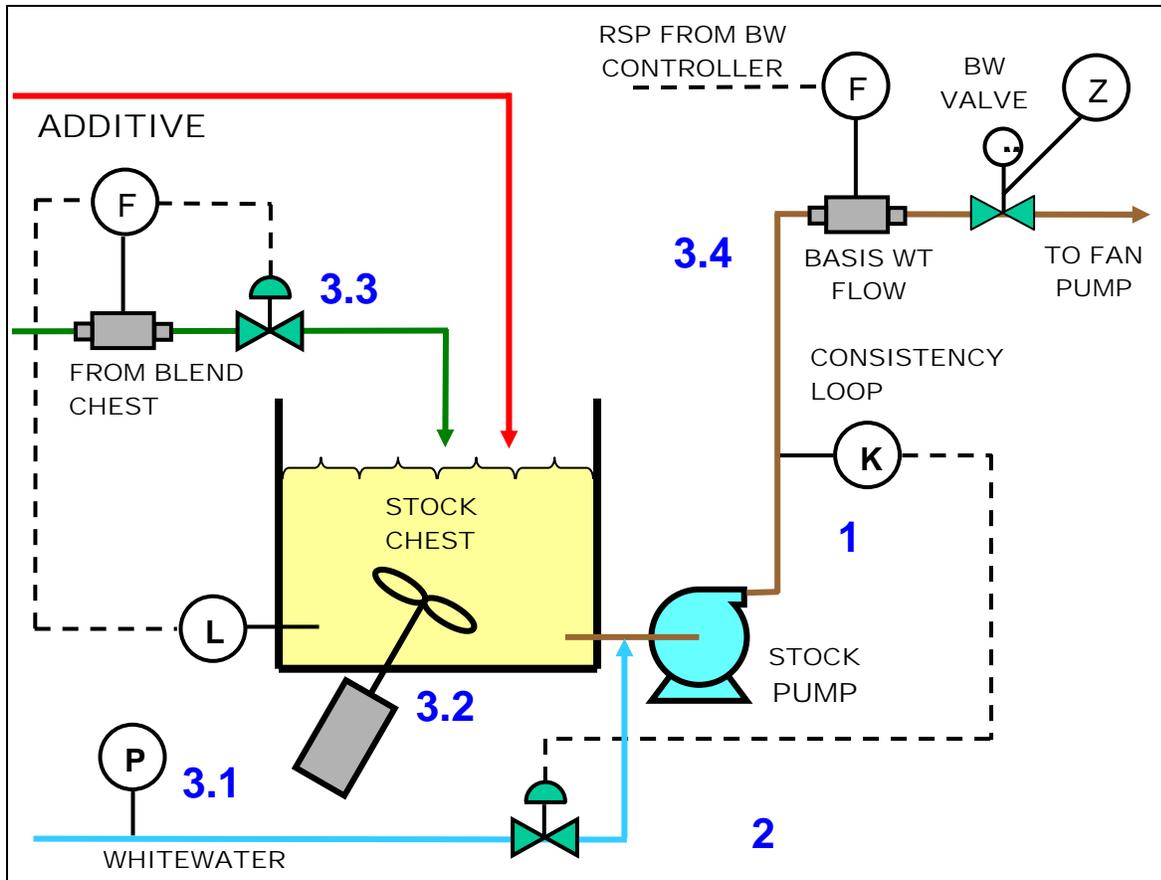
Figure 1 Showing a basic (Simple) consistency control strategy and the equipment that typically surround it.

P1   Transmitters

Consistency transmitters are known to measure just about everything, sometimes even measuring the actual consistency as well! Problems 1-5 below are some of the common measurement sensitivity issues. For feedback control on a steady process (e.g. the amount of ash and air in the stock and the pH and temperature of the stock are constant), these and the lack of absolute calibration (problem 6) are usually not serious problems.   As well, the absolute calibration of the consistency transmitter is not very important for feedback control (but is important for feed forward control).

However, if the process is not steady (we have changing flow, ash concentration, entrained air and conductivity) the true consistency may be poorly controlled due to:

1	Flow sensitivity
2	Insensitivity to Ash, fibre characteristics
3	Air sensitivity
4	Conductivity sensitivity
5	Temperature sensitivity
5	Poor calibration (single point, bad sampling etc.) or simple calibration (non-linear)
6	Improper Installation (not representative sample of the stock)
7	Poor Location (dead time)

This is not intended to be a complete discussion on consistency measurement, but only to give the reader an idea of the magnitude of the problem. For more information see [5].

While problem 7 (excessive dead time) does not affect the quality of the measurement, large dead times can be very detrimental to good control [3].

P2   Actuators and Tuning

The valve should be selected so that the valve tracking non-linearities (such as hysteresis and dead band) are not significant [4] and that the installed characteristics are fairly linear over its operating range. Should this not be the case, the ability to reduce the consistency variability will be compromised.
The tuning of the consistency control loop should be done to maximize disturbance attenuation and at the same time to avoid excessive dead time resonance: the Lambda tuning method is a most suitable method [3] for this objective. Again, ineffective or inappropriate tuning methods will compromise the reduction in consistency variability.

P3   External Disturbances

1   If the dilution water pressure is not constant (due to other users etc.) then the dilution flow will not be constant and the consistency will vary.
Dilution water consistency should not be a problem (as it is small compared with the feed consistency), but a fines cycle (due to a poorly working Saveall) could introduce an uncontrollable problem (as most consistency transmitters cannot measure fines).
2   Tank mixing upstream should remove the fast disturbances that the consistency control cannot. However if the tank is poorly mixed, the attenuation of fast disturbances will be much less than expected and worse still, the poorly mixed tank may actually induce consistency variability.
3   Upstream consistency disturbances (upstream of the feed tank) if slow enough will be seen at the consistency transmitter. Removing the slow upstream (feed) consistency disturbances is what this loop is designed and expected to do.
3   Large changes in demand flow will have a significant effect on the process gain, dead time and time constant. It is the effect of varying demand that makes consistency control such an interesting problem.

CONTROL STRATEGY OBJECTIVES

Consistent with the Process Objectives discussed previously, the Control Strategy Objectives for consistency loops are to keep the demand consistency as constant as possible for all operating conditions and constraints.

The EnTech approach to satisfying the Control Strategy Objectives has the following recommendations:
1   Keep the strategy as simple as possible: As long as it satisfies the control objectives, a simple strategy will be less expensive to implement and easier to understand.
2   Keep the strategy and the process as linear as possible: Actuators should have little hysteresis and dead band, minimal overshoot. Controllers should not use dead bands. Strategies that result in constant process parameters (process gain, time constant and dead time) under all operating conditions are preferred. Such processes are most appropriately controlled by a linear controller (such as a PID controller).
3   Minimize the process dead time. This will minimize variability amplification due to dead time resonance.
4   Use Lambda tuning: This means to tune for fast yet robust (non-oscillatory) dynamics, keeping the dead time resonance below 1.25. The control loop should be stable over all the operating range.
5   Keep filtering of the process values to a minimum: Heavy filtering hides process variability that might be minimized by the control loop.
6   Interactions between loops should be avoided: These can be minimized by tuning or by employing decoupled controllers.
7   Fix potential disturbances at their source. Controllers can only attenuate (but not eliminate) variability, and are only really effective with slow variability so it is much preferred if the source of the variability can be eliminated.

POTENTIAL TYPES OF CONTROL / STRATEGIES

There are several ways with which one can satisfy the control strategy objectives for the different types of consistency processes and at the same time, avoid many of the potential problems.

Because consistency is primarily a mass transport process, it is straight forward to develop simple models that can be used to understand the properties of the process. This paper will develop them only for the basic consistency loop, (a more comprehensive development can be found in [6]), and assuming reasonable/typical values for the model parameters, will calculate the open loop process responses.

S1   Simple or Basic Strategy

Figure 2 shows the basic consistency loop.
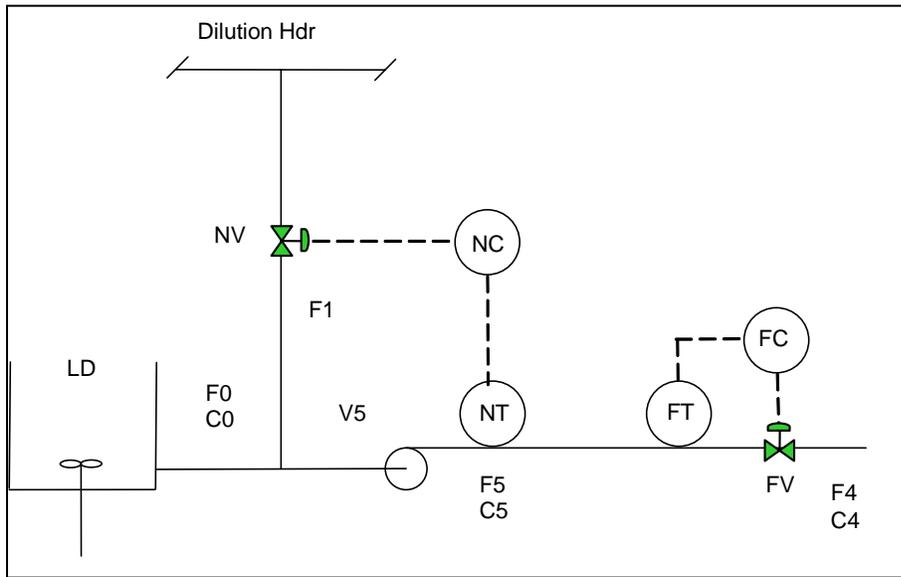
Figure 2   Simple (Basic) consistency control strategy

For a process of this type we will assume the following:

C0	Consistency in the chest = 6.0 %Cons
F0	Flow of stock from the chest
F1	Flow of dilution water through the consistency control valve
Kp1	Dilution flow process gain (assumed to be linear) = 19 LPM/%Output
	(5 GPM/%Output)
F3	Recirculation flow (see Fig. 12 only)
C4	Downstream Consistency (of the demand flow) = 5.0%Cons
F4	Demand Flow, Normal= 6000 LPM (1600 GPM)
F4	Demand Flow, Low= 2000 LPM (530 GPM)
F4	Demand Flow, Very Low = 600 LPM (160 GPM)
V5	Volume between dilution point and Consistency transmitter = 850 L (225 Gal.)
F5	Flow at the consistency transmitter (which in this case = F4)

If we do a mass balance on the process for the liquid and for the fibre, we have:

$$F4=F0+F1 \qquad \text{Liquid balance}$$
$$F4*C4=F0*C0 \qquad \text{Fibre balance}$$
$$\text{(assuming the consistency of the dilution water to be 0.)}$$

Thus C4=F0/(F4)*C0 = (1-F1/F4)*C0

If the installed valve is linear, than F1=Kp1*O1

Since the process dead time is simply the volume in the pipe between dilution point and transmitter divided by the flow, the process gain Kp is $\Delta C4/\Delta O1$, and the time constant of the consistency transmitter dominates the consistency response, we can calculate or estimate the parameters that describe the Open Loop response of this control loop:

Kp= -(Kp1*C0)/F4   The process gain for the consistency process Gp
Tau = Tc Xmitter The time constant of the consistency transmitter, typically 2 seconds.
Td = V5/F4   The dead time of the consistency process Gp

It is clear that both the process gain Kp and the dead time Td change greatly with changing demand flow (F4). A block diagram of the consistency loop is shown below:
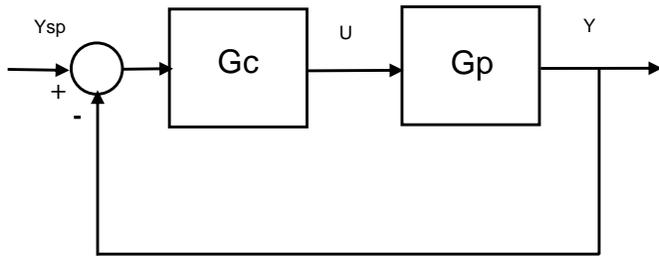
Figure 3   The block diagram of the Simple consistency control strategy (S1) where Gp is the transfer function of a first order process with dead time and Gc is the transfer function of a PID controller.

The following are the responses of the consistency loop to an open loop bump of the controller output:
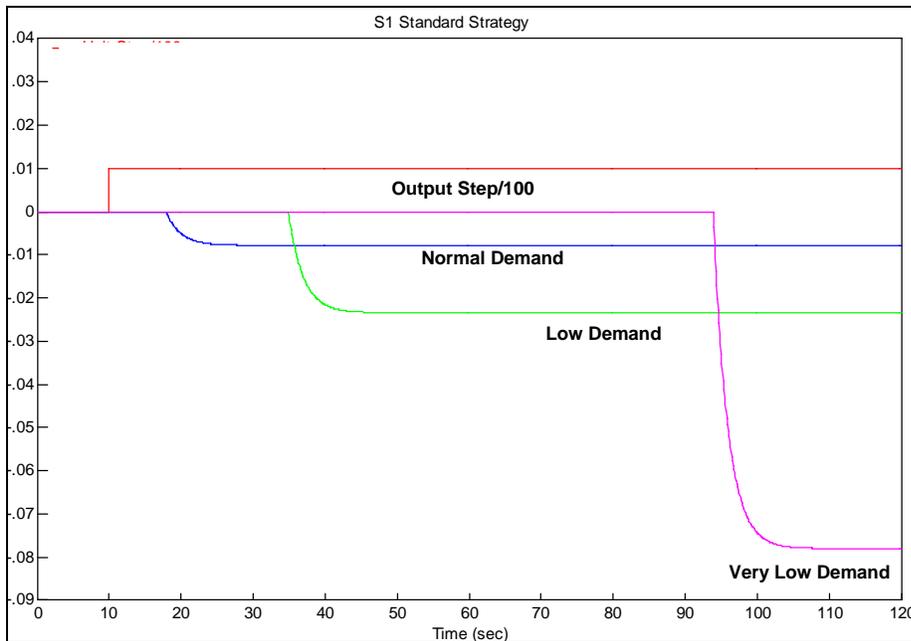
Figure 4 Showing the Open Loop responses of consistency for normal, low and very low demand flow for the controller output step change in the S1 Strategy

Note that as the demand decreases, both Td and Kp increase (the process is not linear). This means that a linear (PI) controller will not perform well for significant demand changes.

Features: It is the least expensive and easiest to understand and maintain.
Limitations: The performance deteriorates if the turn down in the flow demand is greater than 2:1.
Assumptions: Lambda tuned PI controller is used. The Dilution Water supply is stiff (a dedicated pump or pressure controller) so variability due to variations in Dilution Header pressure is small.

This strategy is well discussed in the "Consistency Control Loop Dynamic Specification" [3]. The major limitation with the simple strategy is the problem of coping with turndown of the demand flow.

Using a high fidelity realistic non-linear simulation, the control with different turndown demand is demonstrated in the following figure. Note that below the turndown of 2:1, the control loop is unstable.
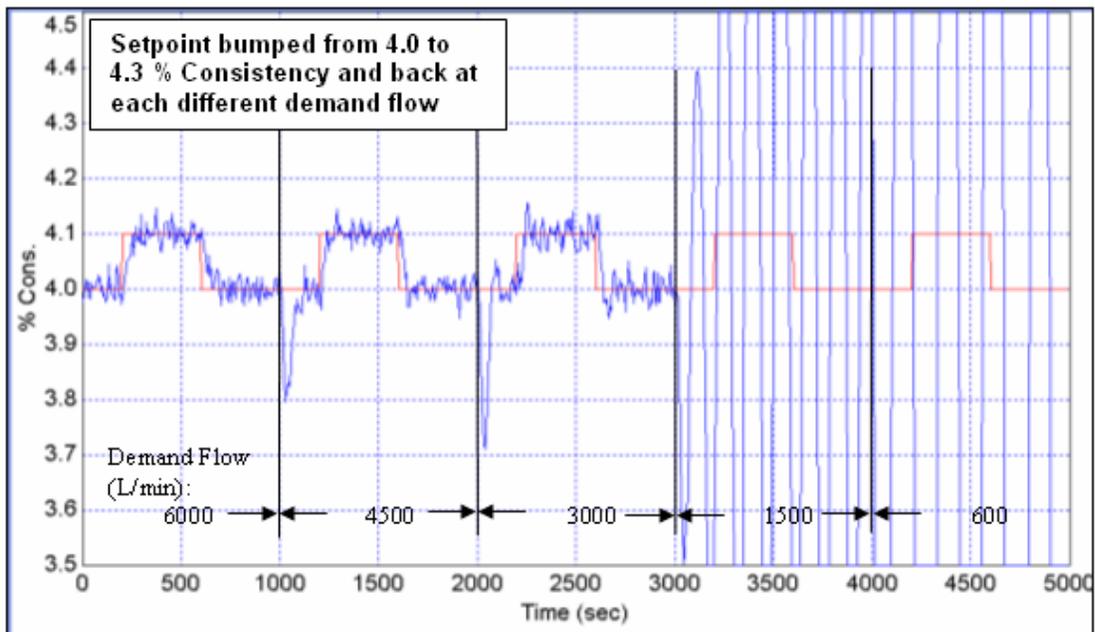
Figure 5   Showing the results using a high fidelity process simulation of a series of consistency setpoint bumps with the basic configuration (S1). During the run the demand flow is lowered in steps from 6000 L/min to 600 L/min. With demand below 3000 LPM (a turn down of 2:1) the consistency loop is unstable**.**

S2   Adaptive gain

The process diagram is the same as Figure 2. And the block diagram is shown below where Gf determines the controller gain and reset time based on the Demand flow setpoint:
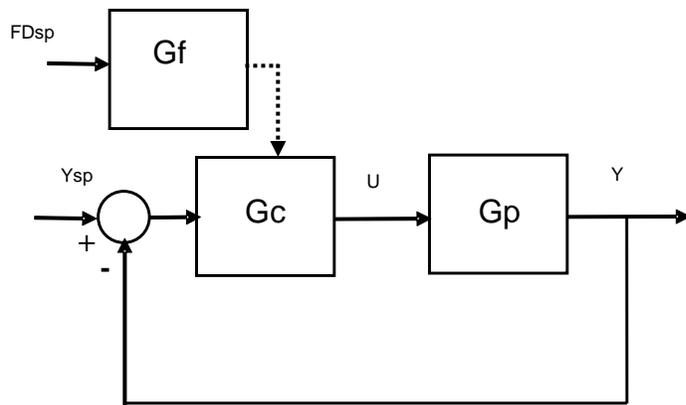
Figure 6   The block diagram of the Simple consistency control strategy with adaptive gain (Strategy S2)

Features: It is only marginally more expensive than strategy S1 and it remains stable with demand flow turndown of 4:1.
Limitations: Dilution water pressure disturbances not addressed.
Assumptions: Same as S1; It is assumed that the sluggish tuning at the low flow is acceptable.
**Discussion:**
        If we consider a factor of 4 change in demand flow, the process dynamics will change: Kp and Td will all increase by a factor of 4.

        So for example, if we start under normal flow (maximum) of 6000 LPM with Kp = 1%S/%O and Td = 5 sec with Lambda = 15 sec., and drop the flow down to 1500 LPM, then Kp= 4%S/%O and Td =20 sec. For a robust tuning, Lambda would have to be 60 sec. In many low demand flow cases, the response will be too sluggish. Figure 7 illustrates the closed loop response of adapted consistency control under several different demand flows.

The best implementation is to adapt both Kip and Try [1]. Some variants adapt only the process gain (or characterize the output of the controller) and so the result will be no better than Flow Ratio control, discussed in the next section.

Figure 7 Showing the results of a series of setpoint bumps with the adaptive control configuration (S2). When the demand flow is lowered, the loop's tuning is adjusted. Note how sluggish the PV is in tracking the setpoint at lower flows.

S3   **Flow Ratio**

This control is illustrated in the following figure:

Figure 8 Strategy S3: Consistency loop controlling the ratio of dilution flow to demand flow

In this strategy, the Dilution flow (F1) is measured and controlled and its setpoint is determined from the Demand Flow (F4) and the Flow Ratio setpoint. The Flow Ratio setpoint is the output of the consistency control loop. Figure 9 shows the block diagram and Figure 10 the open loop responses of the strategy
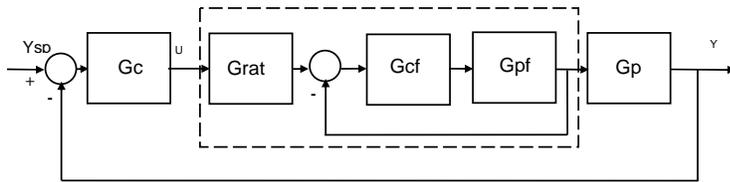
Figure 9 The block diagram of the Flow Ratio Consistency Control Strategy **(S3)**

Features: This strategy linearizes the consistency process so that the gain is constant, independent of flow; can cope with dilution pressure changes; problems from dilution valve tracking non-linearities are minimized; the control is stable with a turndown of 3:1.

Limitations: Having an inner flow loop means that the outer consistency loop may have to be slower than it would have been; The strategy is more complicated and requires more equipment including a flow meter. The process dead time still varies with demand flow, and may make for poor performance.

Assumptions: Dilution Flow loop is Lambda tuned with a small value (should be Lambda of ~ 5 seconds or smaller); setpoint for it is derived from the flow ratio setpoint (calculated by the consistency loop) and the demand flow setpoint (not the MV).

Discussion:

Variant1: Make the Flow control a Proportional only controller: This is very fast and won't affect the dynamics of the outer consistency loop [2]. This does not eliminate valve tracking non-linearities, but does cope with dilution pressure changes.

Variant2: Use Pressure Feed forward
Here one takes advantage of a good dilution valve with a modern digital positioner, having tight positioning tolerances and an accurate Cv curve.
Since $Cv(Op)=F/\sqrt{\Delta P}$, by measuring the dilution header pressure and from it estimating the pressure drop across the dilution valve (delta P), knowing the Flow setpoint we want (F), we can use the Cv curve to back calculate the valve position (Op). This has very fast dynamics, with constant process gain. This loop however will not overcome valve tracking non-linearities (hysteresis, dead band), but with a modern digital positioner, one can make certain that this never becomes a problem. This strategy variant does not require a flow meter.
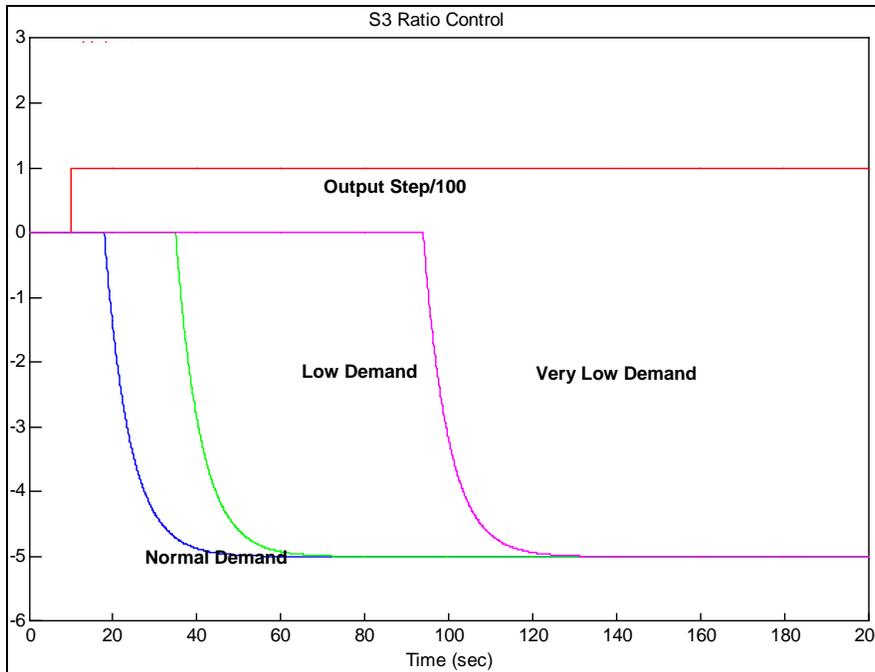
Figure 10   Showing the Open Loop responses of consistency for normal, low and very low demand flow for the controller output step change in the S3 Strategy

Note that the process gain is constant over all demand flow ranges but the dead time varies greatly. Figure 11 shows the closed loop response for different demand flows.
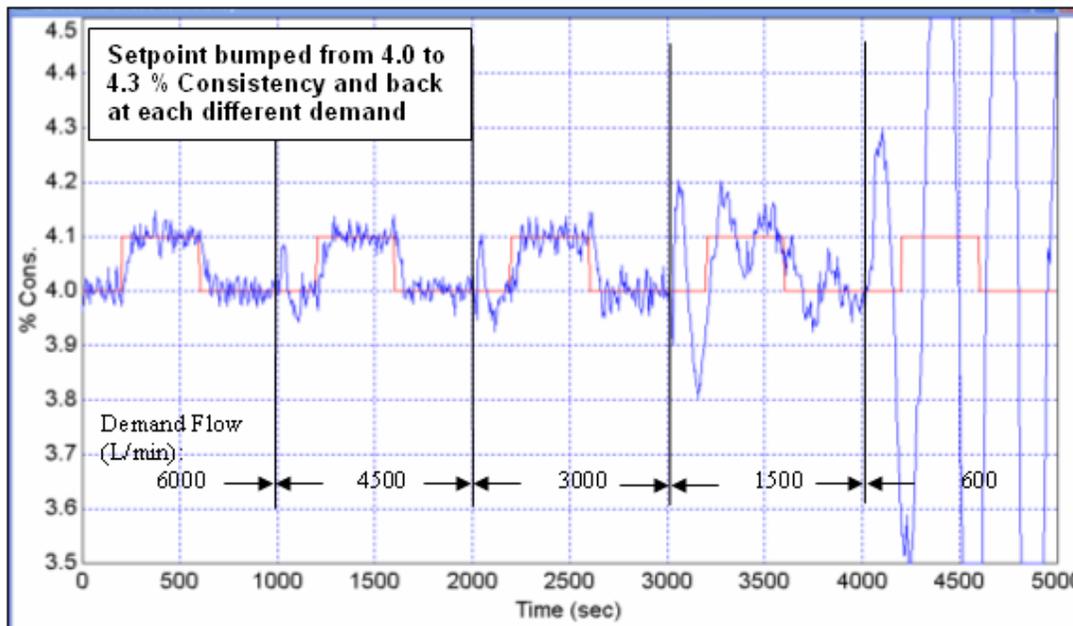

Figure 11   Showing the results of a series of setpoint bumps with the flow ratio configuration (S3). During the run, the demand flow is lowered from 6000 L/min to 600 L/min

S4   Recirculation with Pressure Control

In this strategy, the line pressure is held constant by adjusting a recirculation valve. It is shown below:
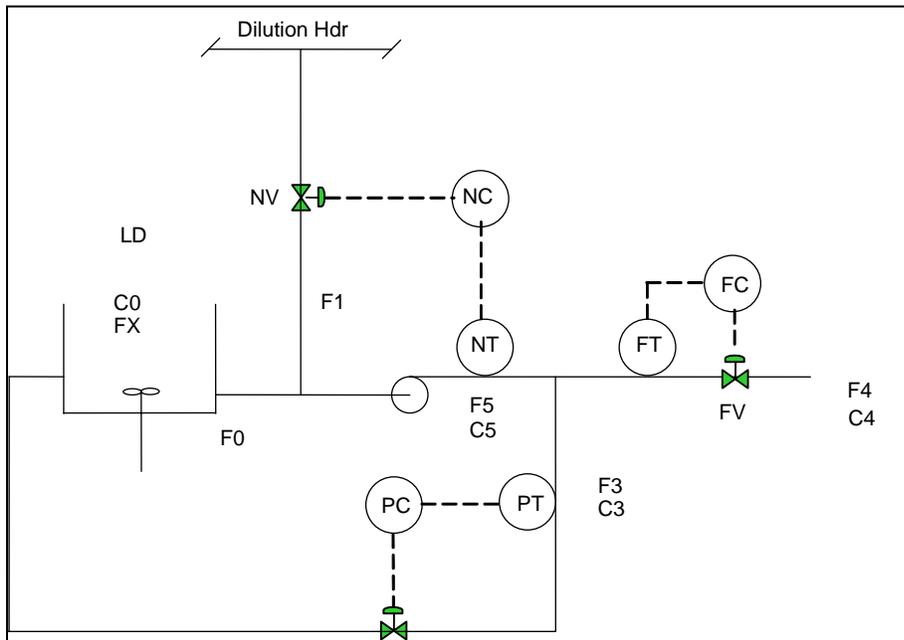
Figure 12   Strategy S4: Conventional consistency control with pressure controlling the recirculation back to the stock chest
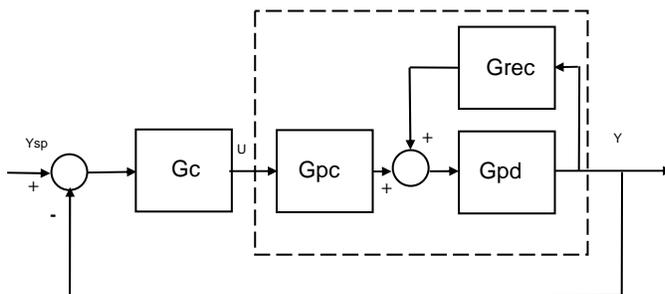
**Figure 13**   The block diagram of Consistency Control with Recycle to Tank Strategy S4

Features   For all different demand flows, the short term response of consistency is linear: Kp, Tau and Td are constant and Td remains small (see Fig. 14 and 15). Thus a turndown of 10:1 is achievable. The stock velocity at the transmitter is constant for all demand flows: this avoids the problem of a consistency transmitter being sensitive to flow; This process strategy can improve the mixing in the tank due to the recirculation flow.

Limitations: Exposed to valve tracking non-linearities; Consistency in the tank will vary (this bothers some operators – but unless poorly implemented will keep the tank consistency equal to or greater than the demand consistency); When demand is low, the response to a valve change will have a very slow, very large long term component (which the control system can control out).

Assumptions: They are the same as S1; Suitable startup and shutdown logic is required so that the dilution valve closes when there is no demand (even when off control)

Discussion:

   Variant: The flow through the dilution valve can be linearized by a flow loop (S3 style) or by a feedforward pressure loop (S3 Variant style).
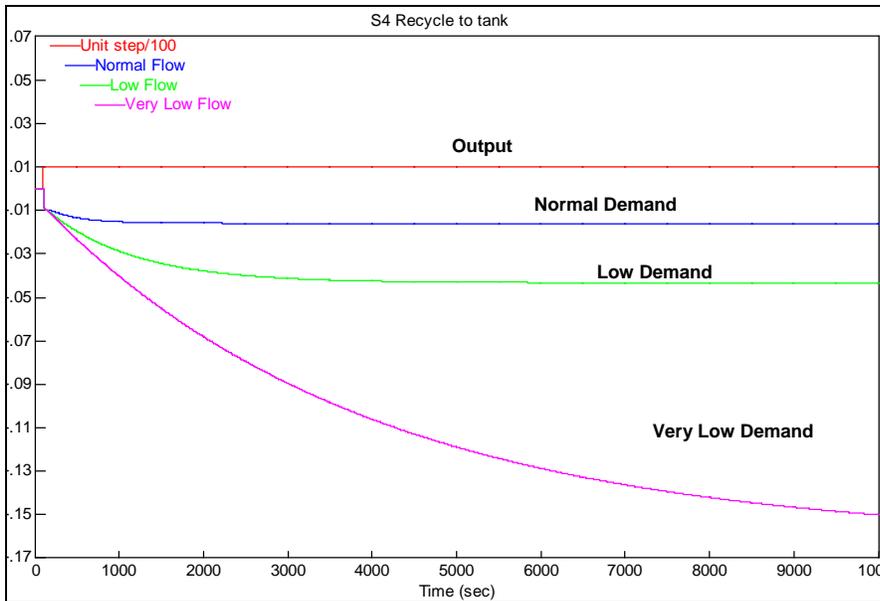
Figure 14   Showing the Open Loop responses of consistency for normal, low and very low demand flow for the controller output step change in the S4 Strategy. Note the 10,000 second time range.
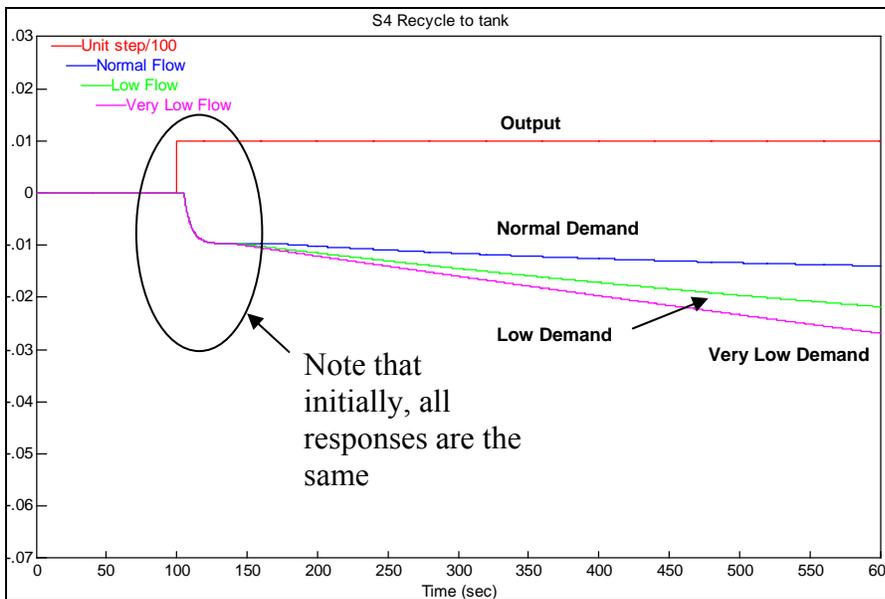
Figure 15   Same as Figure 14, but showing a shorter time scale

Figure 14 shows the long term response (with very different gains for different demands) and Figure 15 shows the short term response with the gain, dead time and time constants all the same independent of demand flow. This means that if the loop is tuned for the short term response, making the long term response appear as a disturbance to control out, a single set of tuning gains will work satisfactorily independent of the Demand flow. This is illustrated via simulation in the following figure:
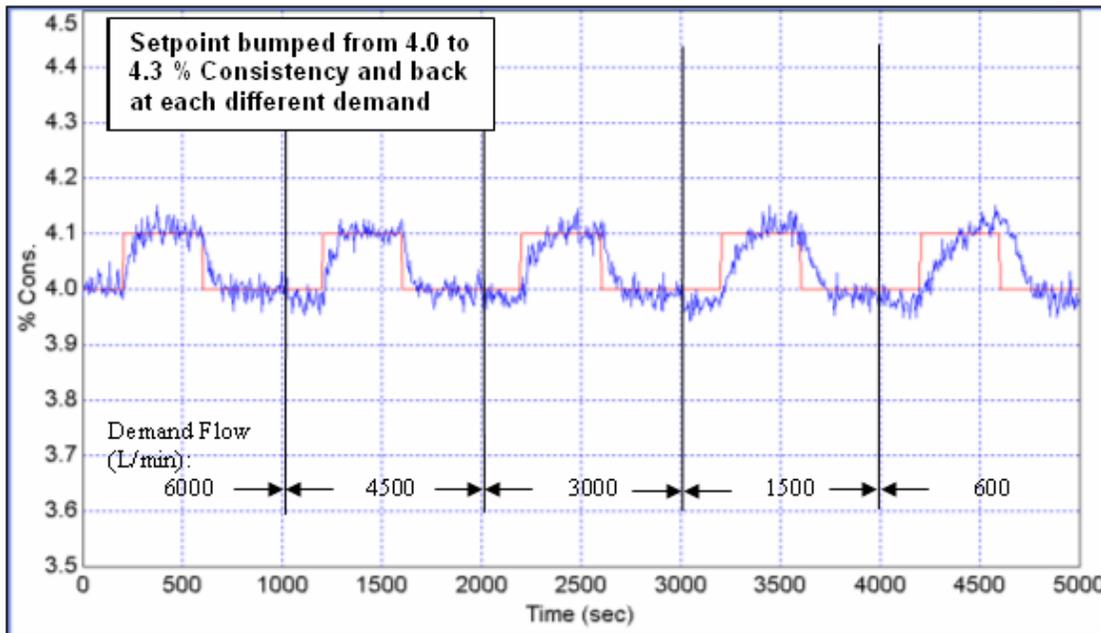
Figure 16 Showing the results of a series of setpoint bumps with the recycle to pump configuration (S4). During the run, the demand flow is lowered from 6000 L/min to 600 L/min

DUAL DILUTION

Dual dilution is required when it is desirable to go from essentially unmixable stock (12% or greater) down to that which can be easily mixed and moved to the downstream processes (7% or less). This would be typical of a High Density (HD) storage chest. The major consistency cut occurs in the base of the HD chest (the Mixing Zone) where a large flow of dilution water is provided usually at the top of the base around the HD chest.

The process objective is still to provide uniform consistency in the demand (downstream) flow of stock. To achieve it for the HD chest, one needs to keep the mixing zone consistency low enough with enough agitation so that the high density stock gets properly mixed in the mixing zone before being pumped down stream (the actual maximum allowed consistency in the zone will depend on geometry, agitation and stock type): When the consistency is high and the mixing poor, it is not uncommon to see the measured consistency going from PV Max to PV Min and back again as "clumps" of stock are pumped along with the water.

Similarly to S1, we have:

|		
C0	Consistency in the chest (above the mixing zone) = 13.0 %Cons	
F0	Flow into the Mixing Zone of the chest	
F1	Trim Dilution Flow	
F3	Recirculation Flow (Fig. 12 and 19)	
C4	Downstream Consistency (of the demand flow) = 6.0%Cons	
F4	Demand Flow, Normal=	6000 LPM (1600 GPM)
F4	Demand Flow, Low=	2000 LPM (530 GPM)
F4	Demand Flow, Very Low = 600 LPM (160 GPM)	
V5	Volume between dilution point and Consistency transmitter = 850 L (225 Gal.)	
Kpf	Dilution flow process gain = 19 LPM/%Output (5 GPM/%Output)	

And in addition:

F5	Flow by the consistency transmitter = 7500 LPM (2000 GPM). For S6 only
CX	Consistency in the mixing zone of the HD chest (target <8%)
VX	Volume of Mixing Zone = 20,000 L (5300 Gal.)
F6	Zone Dilution Flow

S5   Simple Mid Ranging.

Figure 17 shows a typical process diagram of the Simple Consistency Control with Mid-Ranging and Figure 18 shows the block diagram of it.
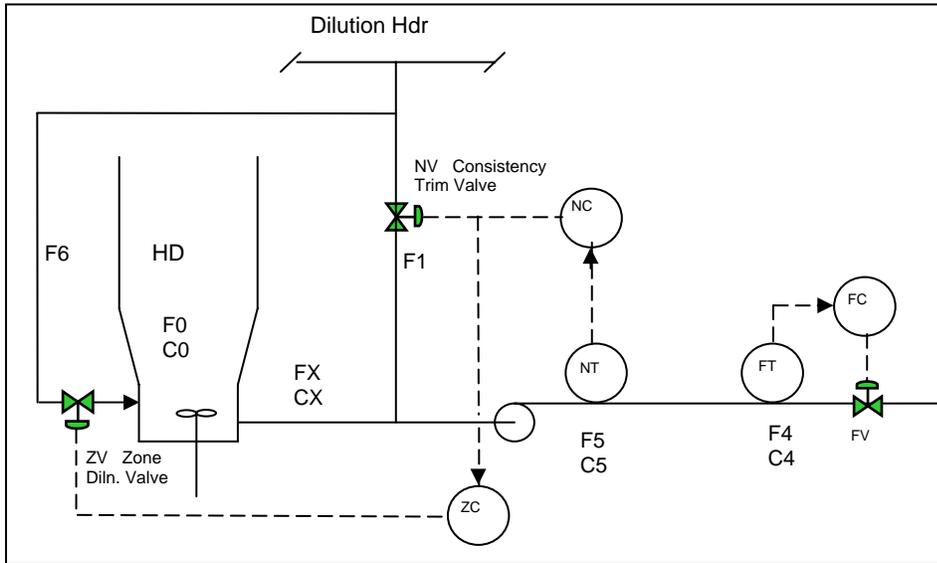
FIG. 17 Strategy S5: Dual Dilution Consistency Control with a Tower (Zone) dilution flow Mid-Ranging the Trim Dilution valve (control loop Zc)
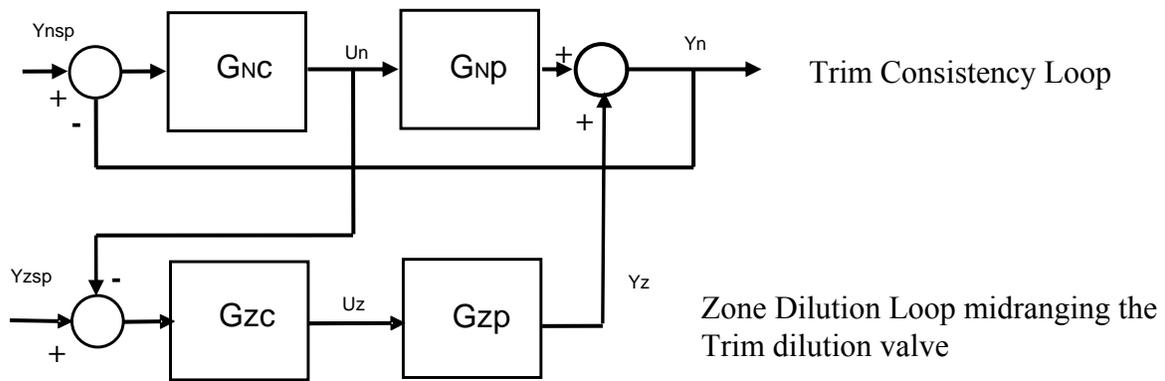
c
Figure 18   Strategy S5 - Simple Dual Dilution Consistency Control using a trim valve with a Tower Dilution mid-ranging the trim valve

Here the Midranging loop, whose task it is to keep the trim valve at target (usually 50 % Open), is tuned slowly so that changes do not suddenly affect the down stream consistency measurement.

Features: This strategy is low cost and easy to implement. It is able to maintain a constant consistency in the mixing zone when the consistency of the supplied HD stock varies.

Limitations: This strategy has all the same problems as the Simple Strategy (S1). As was noted for S1 the turndown could be no higher than 2:1. However, in addition, this strategy cannot keep the consistency in the mixing zone constant when demand changes: for example, a turn down of 1.6:1 (to a demand flow setpoint of 3800 LPM (1000 GPM) from 6000 LPM (1600 GPM) results in a mixing zone consistency of

8%, and at a turn down of 3:1, the consistency in the mixing zone is >11%cons (see Figure 19). For sudden changes in demand flow, the zone flow will adjust only slowly (typically with a time constant of 1-2 minutes), allowing the possibility of poor mixing (and hence excessive consistency variability).

Assumptions: The two dilution flows are not tightly coupled. This may not always be the case, as a change in the tower dilution flow is seen to have a big impact on the trim dilution flow and hence the short term consistency.

Discussion

Note that at Low Demand, the consistency in the Mixing Zone is ~11%Cons., and long before the Demand flow reaches Very Low flow, the Zone dilution valve will be closed. This strategy cannot tolerate significant drops in the demand flow.

Variant: There have been many non-working variants that have been tried to cope with changes in demand flow, some of which have never worked, others worked only poorly and a few that actually work reasonably well.

Variant1:   In principle, one could control the consistency using the zone dilution when the demand is low. However the dynamics, which will include a longer dead time (which is 8.5 sec. for Normal demand, 25 sec. for Low Demand and 85 sec. for Very Low Demand.) and as well as the mixing time constant of the dilution zone. This mixing time constant which at Normal demand might be 3 minutes, will be 9 minutes at Low flow and 30 minutes at Very Low flow, making the potential control of consistency from the Zone flow impractical. Figure 20 illustrates the Open Loop results. With such a large time constant (2000 sec) and dead time (100 sec), it is not practical to try to control this process using the Zone Dilution.
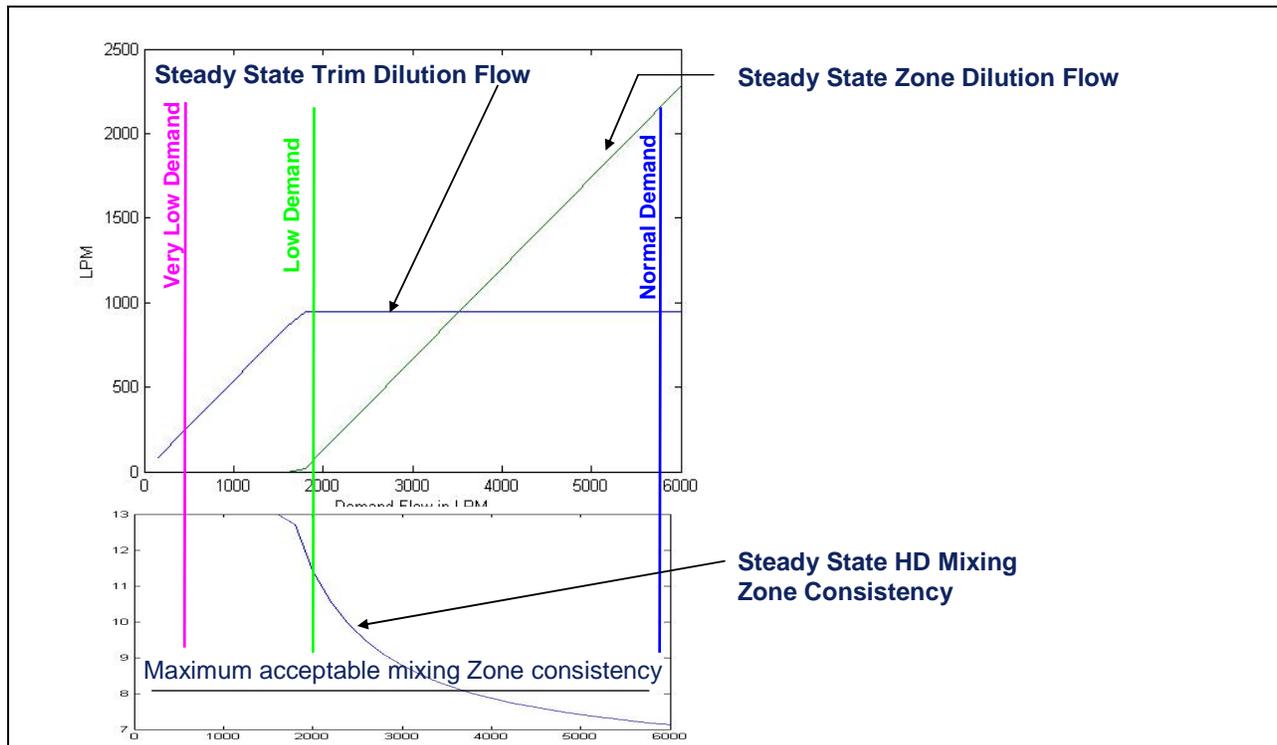

Figure 19   Strategy S5, shown at steady state for a given Demand Flow, the Trim and Zone (Tower) dilution flow and the Mixing Zone consistency: the Tower dilution flow midranges the trim dilution valve (until the demand is so low that the tower dilution valve is closed).
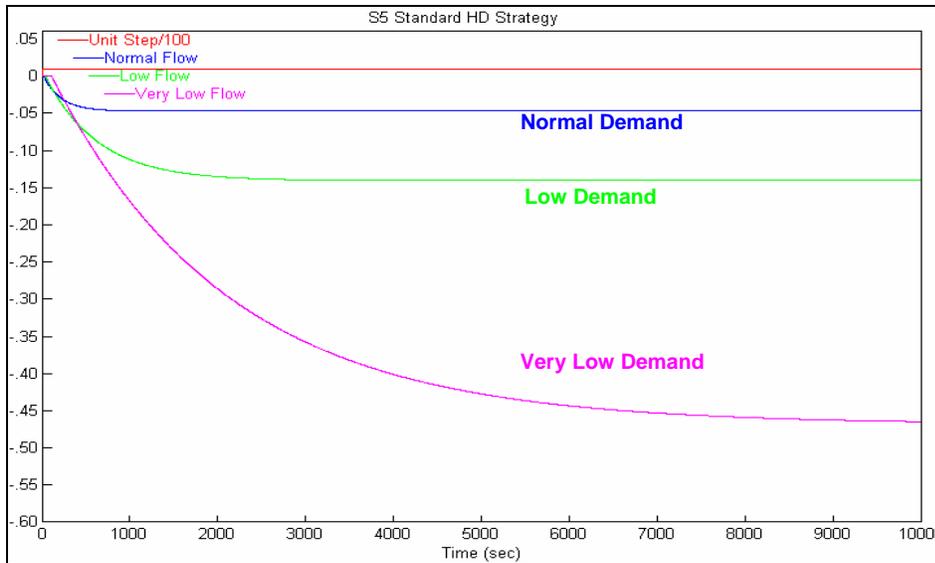
Figure 20   Showing the open loop consistency response to an output change in the Zone dilution valve. Note the very long time constant.

Variant2:   The most serious problem to address in strategy S5 is that of the high consistency in the mixing zone when the demand flow drops (the maximum turndown was seen to be 1.6:1). Using the same strategy (Simple Consistency control with mid-ranging dual dilution), the mixing zone consistency can be kept constant if the consistency cut (Cc which from Figure 21 is Cx-C5) at the trim dilution flow (F1) is constant. This can be done by setting the valve setpoint of the midranger to give a dilution flow F1 = F5 * Cc/(C5+Cc). While this approach solves the variability in the mixing zone, the strategy still has the same limitations as S1, and consequently has a maximum turndown of 2:1. Of course if one adapts the gain of the consistency loop (like S2) a greater turndown (4:1) could be achieved.

Variant3:   This variant is like the above, but runs the zone dilution in ratio to the demand flow (Like S3) and adapts the setpoint of the ratio by the output of the mid-ranging controller (ZC). The setpoint of the mid-ranging controller is established as in Variant2 to give a dilution flow F1 so that the Zone Consistency remains constant. See Fig. 21. Like Variant2 (and S6) this would cope with a turndown of 4:1, but unlike it, the response to a demand flow change would be very quick (around 10-20 seconds).
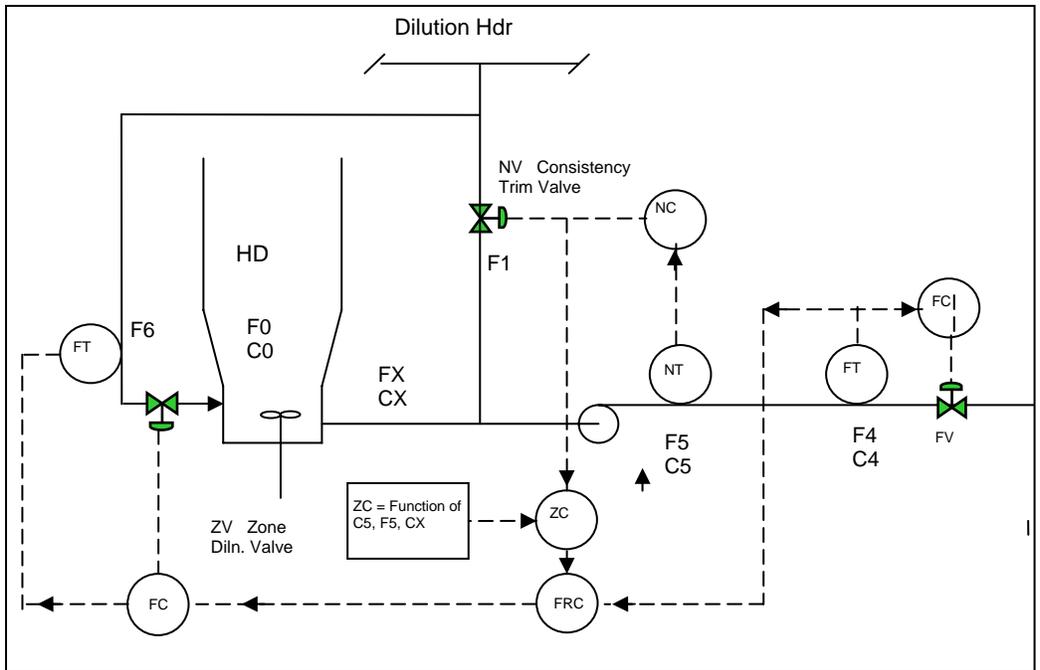
Figure 21 Showing Dual Dilution, Variant3 with Demand flow ratio and adaptive mid-ranging.

S6   Mid Ranging with Pressure recirculation.

The following figure illustrates the strategy of Dual Dilution with Pressure Recirculation and Figure 23 shows the block diagram of the two interacting loops (the block diagram of the pressure control loop is very simple as it is essentially independent of the consistency control loops.
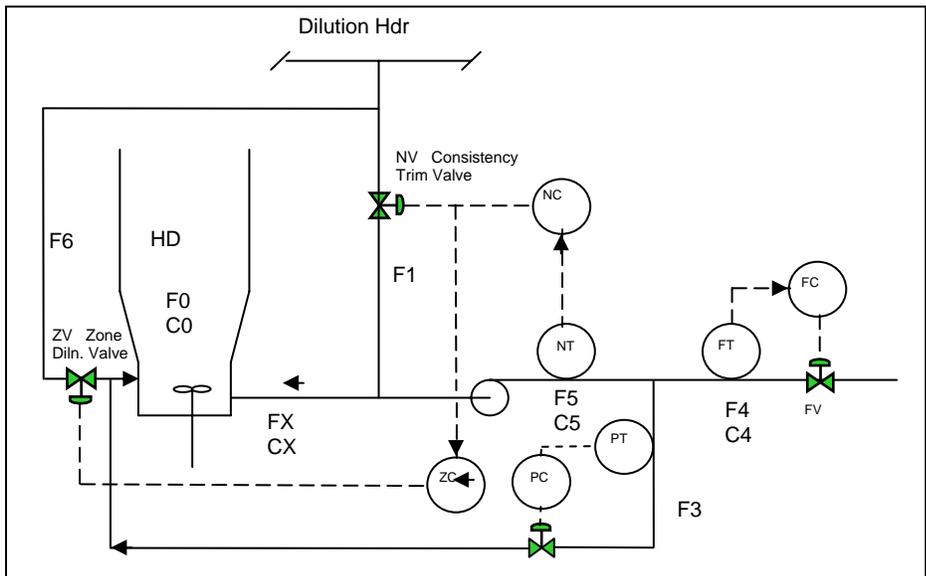
Figure 22 Strategy S6: Dual Dilution Consistency control with pressure controlling the recirculation back to the stock chest

Trim Dilution Consistency Loop

Zone Dilution Loop – midranging the Trim Dilution Valve
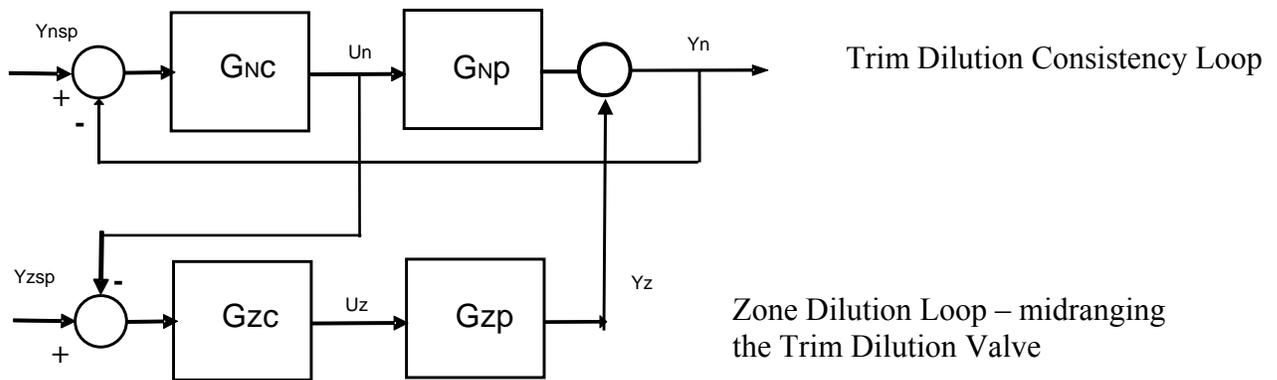
Figure 23   The block diagram of Dual Dilution Consistency Control with Recycle to Tank Strategy S6. But Gnp is the process including the recycle (the dashed box shown in Fig. 9)

Features: Same as with Pressure Recirculation, S4. It will work down to very low demand flow. The Recirculation flow acts as zone dilution when the demand flow is low. Zone dilution is slow, and serves to mid-range the trim dilution valve. This strategy maintains a constant zone dilution (in steady state) under changing HD consistency and downstream demands.

Limitations: Same as with S4

Assumptions: Same as with S4

Discussion: The mid ranging strategy works the same as S5 (see the top part of Figure 19). However, the consistency in the Mixing Zone stays less than 8%, as can be seen in Figure 24 (compared with the bottom part of Figure 19).
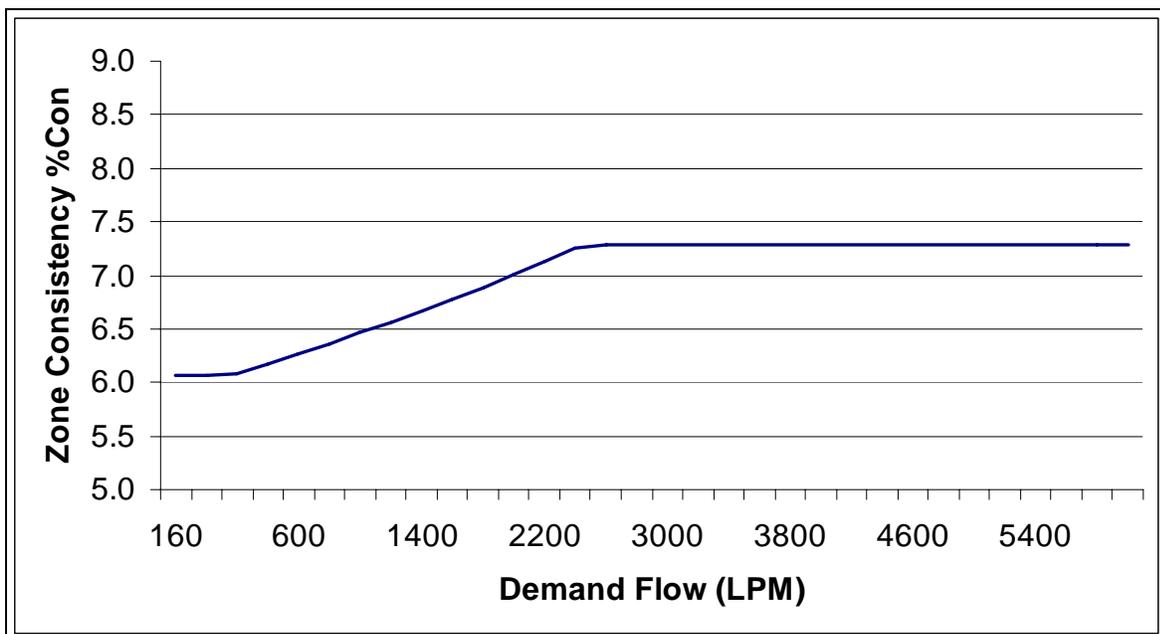
Figure 24   The plot of the mixing zone consistency Cx as it changes with demand flow for strategy S5 (Dual dilution with recirculation)

OTHER CONSIDERATIONS

One may ask, "Why not use Advanced Control?" Used correctly, it may perform as well as the control strategies described in this paper. Used when one understands neither the process, nor its objectives nor the advanced controller itself will almost always result in a costly implementation with poor performance.

However, advanced controls do come into their own when there are multiple interacting loops with possible constraints. Within the venue of consistency control, one can see the need for coordinating multiple consistency setpoints to achieve a water balance that allows all the consistency loops to operate within the control constraints (the output less than 100% open but greater than 0% open).

CONCLUSIONS

Consistency control is neither easy nor is it magic.

However, with a good understanding of the process objectives, and knowledge of linear control theory, the process and control systems can be designed to perform well. This will include:
- The Simple strategy for consistency processes with constant demand flow and a stiff dilution supply pressure
- Dilution flow control or pressure feed forward control for processes whose dilution header pressures vary
- Flow Ratio or Adaptive control where there is significant turn down in demand flow (3:1).
- Consistency Control with Recycle where there is very large turn down in demand flow (10:1) or a significant turn down (2:1) on a high density application.

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For more information:

For more information on Variability Management please visit our website
www.EmersonProcess.com/solutions/VariabilityManagement , or

Contact us at:

email: AAT@emersonprocess.com
phone: +1 512-832-3575

Emerson Process Management
12301 Research Blvd.
Research Park Plaza, Building III
Austin, Texas 78759 USA

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