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OPERATING STRATEGIES FOR VARIABLE FLOW SEQUENCING BATCH REACTORS

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ABSTRACT

Sequencing Batch Reactors (SBR) are variable volume, non-steady state, suspended growth biological wastewater treatment reactors. Their treatment process is characterized by a repeated treatment cycle consisting of a series of sequential process phases; fill, react, settle, decant, and idle. The design and operation of an SBR must take into consideration; 1) the biological process requirement for treating the influent wastewater, 2) the hydraulic requirement to enable the throughput of the water through the reactor without compromising the quality of biological treatment.

During routine operation, the priority between the process and hydraulic consideration can change depending on the influent flow rate and its rate of change. The importance of the interaction between these considerations will vary depending on the fill strategy, and the cycle time control strategy. Where flow proportional cycle times are utilised to optimise the treatment process, the operating strategy must be capable of accurately adjusting the inter-cycle phase times to prevent loss of biological treatment, or volumetric capacity. This paper considers various operating strategies that are required to prevent loss of treatment capacity under high flow rates or where there is a significant rate of change in the influent flow rate.

Key words: ***Cycle time; flow proportional; hydraulic consideration; process consideration; variable flow.***

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INTRODUCTION

Activated sludge has become the most widely used secondary unit process for the treatment of both domestic and domestic wastewaters [(1)]. Arden and Lockett's original investigations in 1913 involved aerating sewage for several weeks before the treated liquor was allowed to settle and the supernatant water was decanted [(2)]. Therefore the very original activated sludge process was operated as a batch reactor and became known as the fill-and-draw process [(3)]. A number of sequential treatment operations were repeated in order to treat the influent wastewater. A reactor was filled with settled sewage and aerated for sufficient time to oxidise the majority of the BOD. Following this aeration period, the aeration was turned off and reactor contents were then allowed to settle so the activated sludge separated from the treated interstitial water. The treated

supernatant was subsequently discharged from the batch reactor. A portion of the settled sludge was wasted and the whole process repeated again.
The development of continuous process quickly led to the abandonment of fill-and-draw systems and their associated operating difficulties [4]. However, with the advent of microprocessor control using programmable logic controllers, a modification of the original fill-and-draw process, known as a sequencing batch reactor (SBR) has emerged as a successful alternative to continuous flow activated sludge plants [3].

PROCESS DESCRIPTION

Sequencing Batch Reactors are variable volume, non-steady state, suspended growth biological wastewater treatment reactors [5,6]. Their treatment process is characterized by a repeated treatment cycle consisting of a series of sequential process phases or events; FILL, REACT, SETTLE, DECANT, and IDLE. The main inter-cycle phase are described below, and illustrated in Figure 1 – SBR General Treatment Cycle Phases.

Fill

The FILL event is where the reactor is filled with wastewater between a low water level and a high water level to provide a treatment batch. The influent wastewater is distributed into the retained settled sludge. FILL can take place under mixed, unmixed, aerated or unaerated conditions [7].

React

The REACT phase starts once FILL is complete [8]. It includes mixing and aeration. Aeration conditions serve to oxidise organic carbon, nitrify ammonia, and promote uptake of phosphorus in the sludge. Unaerated conditions promote denitrification of nitrite and nitrate.

Settle

When the REACT phase ends, SETTLE begins. The SETTLE phase is when all the mixing and aeration is turned off and the mixed liquor suspended solids (MLSS) settle, allowing a clear supernatant to form in the upper part of the SBR. The duration of SETTLE can be adjusted to compensate for sludge settleability.

Decant

Once SETTLE has been completed, the clarified liquid is withdrawn from the reactor and discharged during DECANT. The DECANT phase occurs after a substantial depth of supernatant has formed. Automatic valves open, and the supernatant is decanted from the upper portion of the tank.

Idle

The IDLE phase is the buffering period between the end of DECANT, and prior to the reactor being called to FILL again at the start of the next cycle. The IDLE phase is an optional phase depending on the design of the SBR. It can be eliminated when an influent balance tank, holding tank, or some other method of handling excess flow is available [5]. It can also be eliminated where two or more reactors are used, and the reactors are operated with fixed cycle times.

Sludge wasting normally takes place after SETTLE as the MLSS will have reached its maximum solids concentration, but can take place near the end of REACT, during SETTLE, during DECANT, or during IDLE, and can take place weekly, daily or during every cycle. In some variable-volume activated sludge systems there is no distinct REACT phase, and SETTLE and DECANT occur while influent enters the system [5,9]. In addition to the main inter-cycle phases described above,

depending on the desired level of treatment required, or the fill strategy utilised, a number of sub-phases can be operated. The cycle sub-phases are shown in Figure 2 – SBR Detailed Treatment Cycle Phases, below.

SBR DESIGN CRITERIA

Domestic wastewater is subject to wide variations in flow and load. With the load on a treatment works being dependent on two complimentary characteristics, the first being a quantitative component which is a measure of the volume of sewage, and the second a qualitative component which is a measure of the impurity of strength of the sewage, both of which can fluctuate significantly [10]. Therefore, the SBR has to be designed to cater for these variations. The process design of the SBR system is a function of the influent load, the volume of the reactor, the installed aeration system, and the fraction of the overall cycle allowed for actual treatment steps. Whereas, hydraulically the design of the SBR is a function of the maximum rate of FILL versus the maximum rate of DECANT. The successful design of an SBR must meet the criteria for both process and hydraulic constraints at all stages throughout the cycle irrespective of the influent flow and load. Therefore, the SBR should be designed and operated with a control strategy that can achieve the requirements of both the process and hydraulic considerations. An important and fundamental advantage of an SBR system over a continuous flow system is the flexibility of the process. As the SBR process events are separated by time, rather than space. An operator can potentially modify the duration and sequence of the different cycle events to achieve a desired process modification [7]. Each event can be altered to fine-tune the overall treatment. In addition, the cycle period can be shortened or lengthened if necessary [8]. However, this operational process flexibility has to be carefully altered so not to compromise the hydraulic requirements of the system.

The limiting factor on the design of an SBR will depend on the influent flow and load, combined with the quality of the discharge consent required. Typically an SBR treating wastewater flows up to 3 DWF that arise from a population contributing 180 l/h/d, 60 g/h BOD/d, and 7.5 g NH_3-N/d, and decanting 30% of the total basin volume per DECANT shall be hydraulically limited if the SBR has to achieve carbonaceous treatment only. Whereas, an SBR required to achieve carbonaceous treatment and full nitrification, shall be hydraulically limited when treating settled sewage, but organically limited when treating crude sewage.

Process Consideration

The process volume required to treat the wastewater is comparable to a continuous flow plant, i.e. mass of sludge, to treat mass of pollutant. However there are some important differences in the manner that the process volume is calculated. Firstly, and the most obvious difference is that as an SBR operates as a batch process, the time available for biological treatment by aeration is a percentage of the overall treatment cycle. Also unlike continuous flow plants, SBR's operate with a variable water level. The operational range will be between a low and high water level.

The capacity of each reactor below the design low water level is based on the volume needed to accommodate the process MLSS at the end of the DECANT phase of the cycle. The required biological capacity shall be greater than this volume, and can be determined using similar design considerations to those used for a continuous flow process, such as the sludge loading rate (SLR), and the sludge age [11]. However, SLR's cannot be applied directly as with continuous flow plants. The SLR has to be adjusted for the percentage of the overall treatment cycle in which aeration is permitted. Therefore, although there will be the same oxygen demand as a continuous flow plant, the air will have to be supplied in a shorter time period depending on the fraction of the cycle where aeration is permitted. Also, depending on the fill strategy, the aeration equipment has to

take into account the variable water level to ensure that desired oxygen transfer is always achieved.

Hydraulic Consideration

Once the biological process capacity has been established, the next stage in the design is to check that this volume does not conflict with the hydraulic requirements of the reactor. The volume between the design low water level and the top water level represents the hydraulic capacity of each reactor. Each reactor must have sufficient hydraulic batch capacity to treat the design flow to full treatment [(11)].

The hydraulic consideration must ensure that the ability to move batches of water through the SBR system is always available. In doing this, the reactor must also be able to DECANT treated supernatant under quiescent conditions to prevent settled sludge being entrained into the effluent stream. Failure to do so can result where the hydraulic consideration takes priority over the process consideration in order move water through the SBR treatment stream. If the net FILL rate exceeds the net DECANT rate for significant periods of time, the SBR must have the facility to store or spill water. The hydraulic or batch capacity is a function of the FILL rate, the number of basins in an SBR plant, the number of cycles per day, the DECANT rate, and the DECANT volume compared with the total volume of a reactor. The hydraulic operation of an SBR with discontinuous FILL and DECANT events can be separated into two distinct control strategies:

(1) Fill Control

- (i) Top Down Fill Strategy
- (ii) Bottom Up Fill Strategy

(2) Cycle Time Control

- (i) Fixed Duration Cycle Times
- (ii) Flow Proportional Cycle Times

The operating strategy is a function of both process consideration and the hydraulic consideration and is affected by both the fill strategy, the control of the treatment cycle, and its individual phase events within the cycle.

FILL CONTROL STRATEGIES

Top Down Control

Top Down Control maximises the treatment capacity during the REACT period. The aim is to always achieve the SBR basins top water level to maximise the treatment volume utilised during REACT. This is achieved by varying the bottom water depending on the influent flow rate. So the operational water level in the reactor is controlled from the top down. This control strategy is based on a series of operational water levels, and can only be used for installations that employ a minimum of two reactors. The reactors are operated using the following operational levels:

(1) High High Water Level (HHWL)
(2) High Water Level (HWL),
(3) Normal High Operating Level (NHOL)
(4) Maximum Decant Level (MDL)
(5) Normal Low Operating Level (NLOL)

(6) Low Water Level (LWL)

The HHWL is a fixed level. The NHOL and the MDL are operator adjustable set points, and the HWL and the LWL are the actual levels achieved during operation. The NHOL is a calculated water level under average flow conditions. The MDL is the maximum decant level down from the HHWL required to have the capacity to treat a full batch under maximum flow conditions. Under average flow conditions the reactor will hunt around the NHOL. The control is based on feedback from the operational levels in the preceding reactor at the end of DECANT, and during FILL.

The decanter adjustment calculation steps are shown in Figure 3 – Two Basin SBR Using Top Down Control, and are described below:

1. Store the decant level in the preceding reactor
2. Measure the FILL level in the current basin and extrapolate to give actual HWL
3. HWL – NHOL = Adjustment to DECANT
4. 1-3 = New DECANT level

An example of the variation in NHOL is shown in Table 1 – Water Level Calculation. This variation is based on a typical diurnal variation described by Nicoll (1988) shown in Figure 4 – Typical Diurnal Variation in Flow. The downside of Top Down Control is that it because it is a feedback control strategy it cannot deal with rapid changes in the influent flow rate. Where the variation in flow rate is relatively smooth, the NHOL is automatically adjusted and is maintained between the HHWL and the LWL. However, if there is a rapid increase in the FILL rate, the capacity between the NHOL and the HHWL will be insufficient to accept a full batch, and flow will have to be spilled to maintain a continuous process. Therefore, because of this Top Down control is less appropriate for domestic wastewater treatment where significant diurnal variations can be encountered.

Bottom Up Control

Bottom Up Control overcomes the shortcomings of Top Down Control, but in order to do so cannot make as efficient use of the available treatment volume. Here the SBR's operational water level is controlled from the bottom up. The normal low operation level (NLOL) is fixed, and it is the normal high operational level (NHOL) that varies subject to the influent flow rate. However, to prevent water spills, the NLOL is set such that there is always sufficient capacity to accept the maximum influent flow rate per batch. The downside of this operating strategy is that although any hydraulic variation can be tolerated, the available treatment capacity is only fully utilised under maximum influent flow conditions.

CYCLE TIME CONTROL STRATEGIES

It is not feasible to operate a batch activated sludge process under site conditions without an automatic control system. The requirements of such a control system are that it should be reliable, simple and easily understood by operators [(4)]. A variety of controls strategies can be used that include; fixed; fixed step-change; load proportional; flow proportional; and fully dynamic flow and process proportional cycle times.

Fixed Duration Cycle Times

The simplest systems have fixed cycle times and the reactor is only filled at maximum flow [(12)]. The number of reactors affects the potential cycle length and dictates whether or not an influent balance tank is required. Single reactor systems require an influent balance tank to store water

during the non-FILL events. Two reactor systems can operate without a balance tank if the FILL event extends to half the total cycle length. As the number of reactors increase, the length of FILL can be proportionally shortened. For example, a three-reactor system can be operated as a continuous FILL plant if the length of FILL is fixed at one third of the total cycle length. Figure 5 – Three Basin SBR Using Fixed Cycle Times, illustrates a three basin SBR using fixed cycle times with an overall cycle time of 360 minutes.

In this example, the duration of each FILL event is always 120 minutes, and the duration of the non-FILL events is always 240 minutes. When the first reactor has completed its FILL event, automatic valves simply direct the influent wastewater to the next reactor in sequence. Using Bottom Up Control ensures that the SBR plant can always treat the influent flow rate.

Even when using fixed cycle times, modifications can still be made to the duration of the different cycle events to achieve a desired process modification. Keeping with the above example, FILL can be broken down into sub-cycles such as STATIC FILL and AERATED FILL, and the non-FILL events can operate within a range with logical limits. The combined FILL event duration (sum of times for STATIC FILL and AERATE FILL) will always be 120 minutes. An operator could select the desired STATIC FILL duration, and the AERATE FILL duration would be calculated by the PLC. Similarly, the duration of the remainder of the cycle (sum of durations for REACT, SETTLE, and DECANT) will always be 240 minutes. The operator could select the desired duration of SETTLE and DECANT, within recommended ranges, and the REACT time would be calculated by the PLC. Figure 6 – Typical Three Basin SBR Cycle Ranges illustrates the range of inter-cycle times within a typical 360-minute cycle.

When using fixed cycle times, dissolved oxygen (D.O.) control should be used to avoid over aeration during periods of low organic and hydraulic loading. Also as the separate basins operate as discrete treatment reactors the overall cycle time should not be directly divisible into 24 hours. This is to avoid the possibility of the same reactor always receiving a peak load compared with the other reactors. A variation of using fixed cycle times is where two modes of operation are used, with a step change in cycle times, where shorter cycle times are used for high flows [9,12]. This step change can relate to the influent flow rate to the SBR system, or where an SBR system operates with n-1 basins when a basin has been taken out of service for routine maintenance, or when a basin has failed. For example, a three basin SBR system operating with a 360 minute total cycle time can automatically switch over to operating as a two-basin SBR system with a 240-minute cycle time when a single basin is taken out of service. So even operating with fixed cycle times, process flexibility can be maintained.

Flow Proportional Cycle Times

Moving away from fixed cycle times increases the complexity of the control system required. For instance, cycles can be operated where the basin fills completely at all flows above average flow. To accommodate this, the cycle time has to be reduced inversely proportional to the influent flow rate. With variable cycle times the control system needs to look ahead and ensure that there is always a basin ready to accept feed as required, this usually involves shortening the aeration process times as the flow increases [12]. Reducing the cycle length inversely proportional to the influent flow rate only takes into account the treatment hydraulic consideration. The volume available for treatment is more efficiently used compared to fixed cycle times, as the basins are filled at all flows above average flow, and not just maximum flow conditions. However in shortening the cycle time as flows rise above average flows only ensures that each reactor has sufficient hydraulic batch capacity to move the water through the SBR treatment stream.

The organic and hydraulic loading onto a treatment plant will vary with its catchment. The catchment will be dynamic, depending on the type area served, whether it be; residential, industrial, commercial, academic or tourist, and whether the catchment consists of separate or combined sewers. For a combined sewer system serving a mixed catchment, flow in the sewer shall include a relative magnitude of foul sewage flow, and a relative magnitude of slow and fast response non-sewage inflow and infiltration [12]. The non-sewage inflow and infiltration will provide a dilution rate for the total flow/foul sewage flow.

Therefore, at times of very low flow, the organic load will also be correspondingly low. During these times the REACT period can also be shortened accordingly. So under theoretical catchment conditions, as the hydraulic loading increases up from zero, the organic loading will increase correspondingly. Excluding flash storms, the normal peak pollutant strengths should correspond approximately with normal average flow conditions. Flows above average conditions shall be progressively diluted through non-sewage inflow and infiltration. Therefore as the influent flow rate increases up from zero, the volume of reactor required to treat the influent sewage will increase up to a maximum, at which point the non-sewage inflow and infiltration progressively dilutes the influent sewage strength. This dilution will result in a reduced influent strength, and subsequent reduced batch load. Figure 7 illustrates the variation in cycle times with increasing flow rate. Initially REACT will be based on the minimum aeration required for maintenance air to cover endogenous respiration. Then, as the flow increases, the length of REACT increases up to a maximum, then AERATE FILL increases up to a maximum at 100% design flow. As the flow increases above 100% design flow, the length of REACT is progressively reduced as the influent strength is diluted.

There are a number of methods to achieve proportional control strategies that take into consideration both the process and hydraulic requirements of operating an SBR using dynamic mathematical models, fuzzy logic, or control programmes [14,15]. Yoo et al (2004) described the application of multiway independent component analysis (MICA) to monitor the performance of the SBR process [16]. Hua et al (2004) described a cascade closed-loop control strategy for the optimisation for batch reactors [17]. Pavselj et al (2001) described an experimental design of an optimal phase duration control strategy using a control algorithm using indirect process variables [18]. Whereas, Eco Process and U.S. Filter both supply propriety flow proportional control systems for SBR's [6,19].

Eco Process's BioLog™ is an exhausted flow control strategy developed into a software program to operate the process sequence in a viable manner to keep the biological treatment performance optimum while managing all flow variations. The program was developed by Eco Process and can accept and manage continuous or hourly peak flow periods reaching over 5 times the average flow condition of a plant. USFilter's OMNIFLO® System provides precise process control over a wide range of flows. The microprocessor control system operates on a timed 'batch proportional' program at low flows and a 'flow proportional' program at average and peak flows [6,20].

DISCUSSION

Flow Proportional Cycle Times

The control strategy can be based on the identification of the endpoint after biological reaction. Switching to the next phase shortly after the detection of the reaction endpoint provides an optimum solution for both the process performance and the economies of the plant [16]. This type of control will give rise to flow and load proportional cycle times. Flow proportional cycle times allow for better utilisation of a treatment reactor compared to fixed cycle times. However, the flow proportional cycles are far more complex than the fixed cycle times, and must ensure that there is

no conflict between the process and hydraulic requirements of the SBR. USFilters' OMNIFO® system that uses a timed batch proportional program at low flows and a flow proportional program at average and peak flows is effectively a three-tier control strategy. The timed batch proportional program takes care of the treatment process at low flows. The flow proportional program takes care of the process and hydraulic considerations at higher flows. The process consideration should take care of all treatment operations under normal conditions. With the hydraulic consideration interacting with the process consideration, adjusting cycle lengths inversely proportional to the influent flow rate at flows above 100% design flow. The third-tier is an emergency hydraulic watchdog, which will only be called to operate under certain circumstances to ensure that the hydraulic batch can be moved through the treatment stream. The cycle times should be set up and operated using the timer based program, and the flow proportional process and hydraulic considerations via control set points. Under normal operation the hydraulic watchdog should not be called to operate.

Process Consideration

The aim of the process consideration is to supply sufficient air for biological treatment and provide conditions to achieve of a good settling sludge. Under normal conditions the process consideration has priority over the hydraulic consideration. At the initial design stage, the volume of the reactor is sized taking into account the fraction of the cycle in which aeration is permitted. The aeration period can be extended throughout the FILL and REACT events. Therefore, in a 360-minute cycle it may be possible to extend the aeration period up to about 300 minutes. However, under design conditions the target aeration period will be limited to about 50% of the total cycle time. The OMNIFLO® control system normally operates in the range of 60 to 140 minutes in a total cycle of 360 minutes [(21)], a range of 17 to 38% of the total cycle time. 17% is minimum aeration for endogenous respiration. 38% is the target aeration period for maximum aeration. The process requirements are set up using a number of set points. The typical process set points for a flow proportional SBR are shown in Figure 8, below:

Hydraulic Consideration

The aim of the hydraulic consideration is to ensure that hydraulic batches can be moved through the treatment stream without stopping the treatment process or flooding the reactor. Under normal operation with flows less than 100% design flow the hydraulic consideration will not be called to interact with the process consideration. With flows over 100% design flow, the flow proportional program will ensure that that basins are ready to accept sequential FILLS to maintain a continuous 'batch' process. The hydraulic consideration includes a hydraulic 'watchdog' that may override the calculated cycle times under circumstances where either the set points are not balanced, or where rapid rates of change in the influent flow rate are encountered. The typical hydraulic set points are shown in Figure 9, below:

The hydraulic set points are far simpler than the process set points, as they are only concerned with passing a volume of water through a batch. However, there is direct interaction between the hydraulic and process set points. For instance, the Max Fill set point will have an affect on the overall cycle time, and thus place a constraint on the time available for non-FILL events, before an active basin has to be ready again to accept its next FILL. Under normal operation the time to top water level (T2TWL) is monitored during FILL, and sets whether or not the design flow is above 100%. If the TWL is not reached during FILL, timers control the SBR operation.

Calculation of Cycle Time

Where flow proportional control is used, the calculation of the total cycle time is critical to the continuous operation of an SBR. One of the key aspects is ‘basin ready’ time. This is the time between a basin finishing FILL and going into REACT and when it will be called to subsequently FILL again. The steady-state calculation for basin ready time is simply (Number of basins (n) - 1) x Max Fill Time. This gives the time required to complete all non-FILL events before that basin is called to FILL again. At 100% design flow, the T2TWL should correspond with the Max Fill set point. The Max Fill set point constrains the FILL period, to enable the ‘basin ready’ time to be calculated. If flows are less than 100% design flow, FILL will time out at the Max Fill set point. If flows are in excess of 100% design flow, FILL will be terminated on reaching TWL. In conjunction with the flow proportional program, the time taken for FILL sets the time available for non-FILL events, and predicts the basin ready time. However, in practice the influent flow is not steady state, and the cycle times are adjusted inversely proportional to the influent. There are certain milestones in the calculation process. For instance, the aeration period is calculated and fixed at the end of FILL. So once FILL has ended the ‘basin ready’ time cannot be further adjusted. As the influent flow is dynamic and still may change significantly after the aeration period has been calculated, there has to be a buffer period to absorb these changes. This buffer period is built into the treatment cycle as the IDLE period. If the rate of change is such that there is insufficient IDLE capacity, the hydraulic watchdog will operate based on the T2TWL and force either FILL DECANT or FILL SETTLE events to maintain hydraulic throughput through the SBR. Depending on the flow conditions, three levels of control operate:

(1) Time based treatment operations, with set points:

Max Fill
Max Air
Min React
Settle
& hard coded Decant Time

(2) Flow proportional process and hydraulic treatment operations, with set points

Flow Sample
Anoxic Multiplier
Max Anoxic Time
Settle Safety
Max Decant
Decant Fall
& hard coded Design Flow

(3) T2TWL hydraulic watchdog

The cycle time is ultimately a function of the timer based operations, and the flow proportional process and hydraulic treatment operations, under a variety of flow conditions. The hydraulic watchdog is only used to maintain hydraulic throughput in exceptional circumstances. Table 2 illustrates a typical cycle time calculation.

From the table, it can be seen that at 100% design flow, there is 120 minutes available for REACT, so with a Max Air set point of 114 minutes, there will always be sufficient air time. Therefore REACT will always be terminated on the Max Air set point, i.e. the treatment cycle shall be controlled by batch timers, and the process consideration shall not be required to operate.

Whereas, at flows above the design flow, only 52 minutes is available for REACT, and with a FILL time of only 43 minutes, the Max Air set point of 114 minutes cannot be achieved even if aeration time is forced into FILL as AERATE FILL. As it cannot be achieved, the Max Air set point is not balanced for conditions where maximum flow is encountered. Table 3 shows the effects of adjusting the set point to allow the treatment conditions to be met.

From the table, it can be seen again, that at flow up to 100% design flow, there is still 120 minutes available for REACT, so there will always be sufficient air time. Therefore like the above example, REACT will always be terminated on the Max Air set point. At maximum flow, only 52 minutes is available for REACT. So with a Max Air set point of 82 minutes, to achieve the set point, the process consideration will operate to force 30 minutes of aeration into FILL as AERATED FILL. The OMNIFLO® control system' achieves this through the calculation of the ANOXIC FILL duration. The control of this anoxic time is derived from several factors and set points. The main factor is a propriety substrate utilisation curve derived by Jet-tech that is based on substrate utilisation under anoxic conditions. This has been calculated as the ideal relationship of the incoming flow and load to the amount of anoxic time required to promote ideal selection pressures for non-filamentous organisms to give rise to a rapid settling sludge [22,23,24]. The set points that affect this are:

(1) Max Anoxic Fill
(2) Max Fill Time
(3) Anoxic Fill Multiplier

Figure 10 Illustrates the substrate utilisation curve developed by USFilter/Jet-Tech. The Max Anoxic Fill can be shorter than the Max Fill set point to prevent excessively long anoxic periods under certain flow conditions. The Max Fill sets the time out limit of FILL. The Anoxic Fill Multiplier is used to calculate minutes of ANOXIC FILL. At flows greater than 100% design flow, the process consideration will override the batch timer program, with the anoxic multiplier having priority over the timer-based program. Therefore, it is essential that the set points should be balanced with each other.

Balancing Set Points

The set points have to in balance with each other to avoid conflicts between the process and hydraulic considerations used by the control software. As the SBR process is a continuous cycle, each set point potentially affects another set point [25]. The anoxic multiplier is a process consideration, which takes priority over the timer-based program. The multiplier offsets the above curve to calculate the required minutes of ANOXIC FILL to achieve a good settling sludge. As the anoxic multiplier acts first, it is essential that it be balanced with the Max Air Time, to avoid eating into the required aeration time. The OMNIFO® control system uses an anoxic time of 112 minutes at 100% design flow [14]. Therefore a multiple of this value is used to calculate an anoxic time that corresponds with the overall aeration requirement and the time available for REACT. In the above example, given a FILL period of 43 minutes, of which 13 minutes needs to be anoxic, the anoxic multiplier shall be $13 \div 112 = 0.12$.

Summer & Winter Set Points

As mentioned previously, when using fixed cycle times, a variation of that type of control is where two modes of operation are used. There are step changes in cycle times, where shorter cycle times are used for high flows. These can also be referred to as 'summer' and 'winter' or 'normal' and 'storm' cycle times [26]. These step changes are used to try and use the treatment volume as efficiently as possible over a wide range of flows. The same problem is still encountered even when using flow proportional cycle times. In making sure that the set points are balanced, the

cycle times have to be effectively shortened by reducing the Max Air set point. In doing so will ensure that there are no set point conflicts, but introduces the risk of not being able to provide sufficient aeration for biological treatment.

Fill Decant

Extending the Max Air set point can eliminate the risk of insufficient aeration. However, doing this also extends the overall length of the treatment cycle, and increases the 'basin ready' time. Under conditions where the influent flow undergoes a significant rate of change, there a risk that the IDLE buffer period is insufficient, and a basin will not ready in time to accept its next FILL. If this situation does occur, the control system will divert the influent flow to the most advanced basin in its cycle, and it will have to take the flow. Under these circumstances it is possible that either a FILL DECANT, or a FILL SETTLE event will occur. The Settle Safety set point is used as a hydraulic consideration to try and avoid FILL DECANTS occurring. The Anoxic Multiplier set point is used to avoid a FILL SETTLE [(21)].

CONCLUSIONS

1. The design of SBR's must consider both the process requirement to treat the organic load, and the hydraulic requirement to enable throughput of water through the treatment stream.

2. SBR's can operate with either Top Down or Bottom Up fill strategies. However where variable flows are encountered, Top Down control is not suitable.

3. SBR's can be operated with either fixed-cycle or flow-proportional cycles in order to treat a variable flow.

4. An operating strategy using flow proportional cycle times uses the treatment volume more efficiently than fixed cycle times.

5. Flow proportional process and hydraulic control strategies offer the most complex control strategies, but enable the treatment to automatically adjust to match the flow and load.

6. When using flow proportional software, operational set points must be balanced to avoid conflicts between the process and hydraulic considerations.

7. Under certain flow and load conditions, either all the process requirements, or all the hydraulic requirements cannot be met. Where a long aeration period is required, it may not be possible to operate the SBR without the hydraulic watchdog having to truncate cycle times and force FILL DECANT events.

8. FILL DECANT events can be avoided using design flow or 'winter' set points. These ensure that the plant will always operate within the timer-based program, and the flow proportional process and hydraulic program, without the hydraulic watchdog being called to operate. However, in avoiding FILL DECANT, the aeration period, set by the Max Air set point may not be sufficient for biological treatment.

9. Where variable treatment cycles are used to treat variable flows, irrespective of the control strategy used; dynamic mathematical models; fuzzy logic; control programmes, etc, the control system must use a hydraulic watchdog to ensure that hydraulic continuity can always be

maintained throughout a batch treatment process, otherwise flow attenuation or storage volume must be provided to absorb rapid rates of change in the influent flow rate.

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APPENDICIES

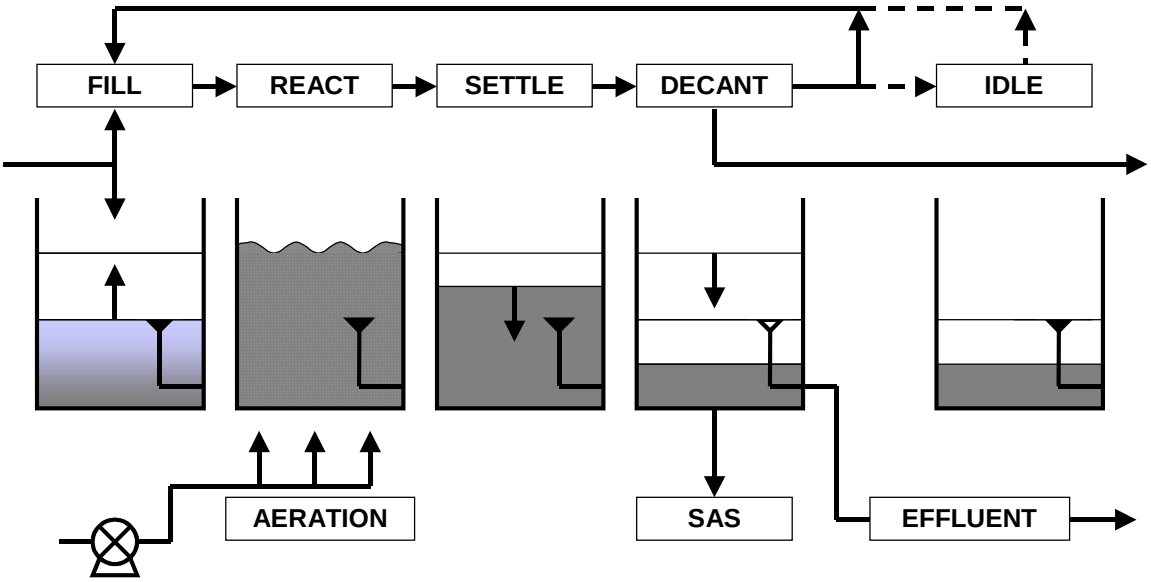


Fig. 1. SBR General Treatment Cycle Phases

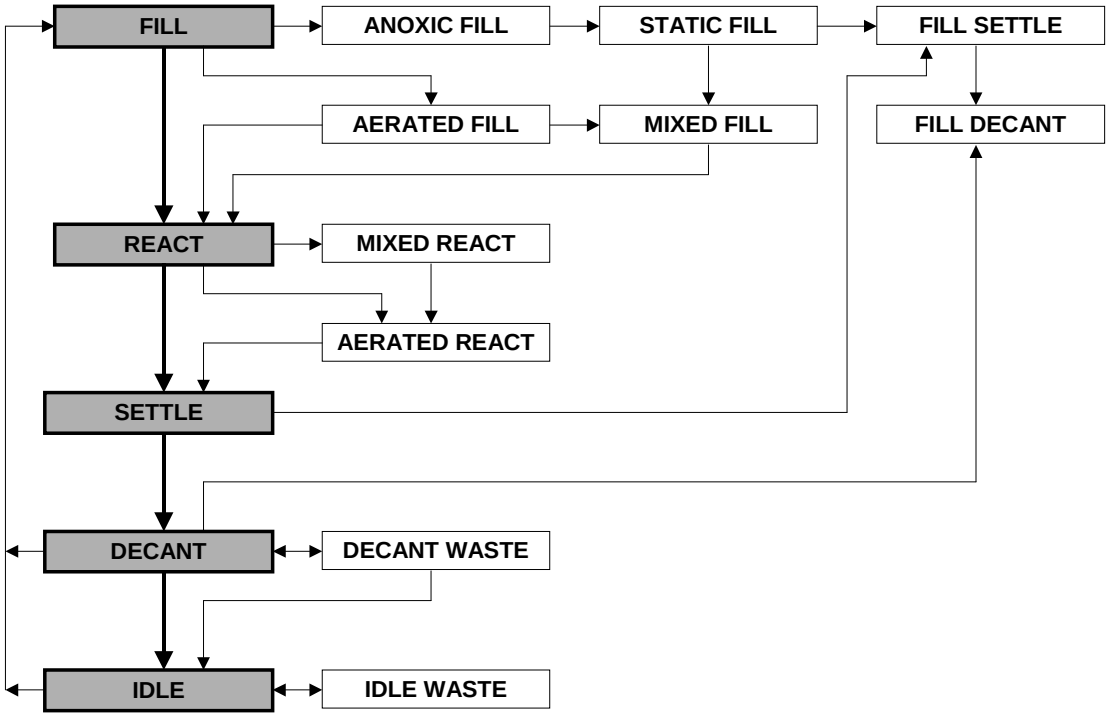


Fig. 2. SBR Detailed Treatment Cycle Phases

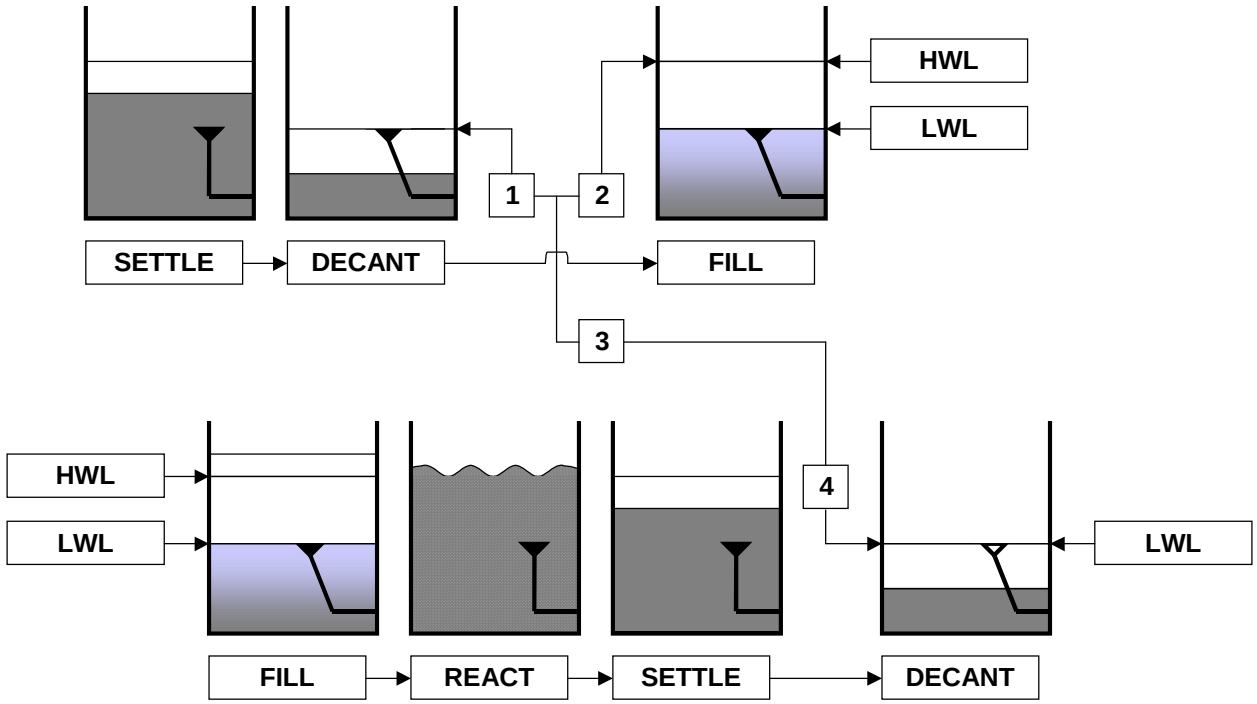


Fig. 3. Two Basin SBR Using Top Down Fill Control

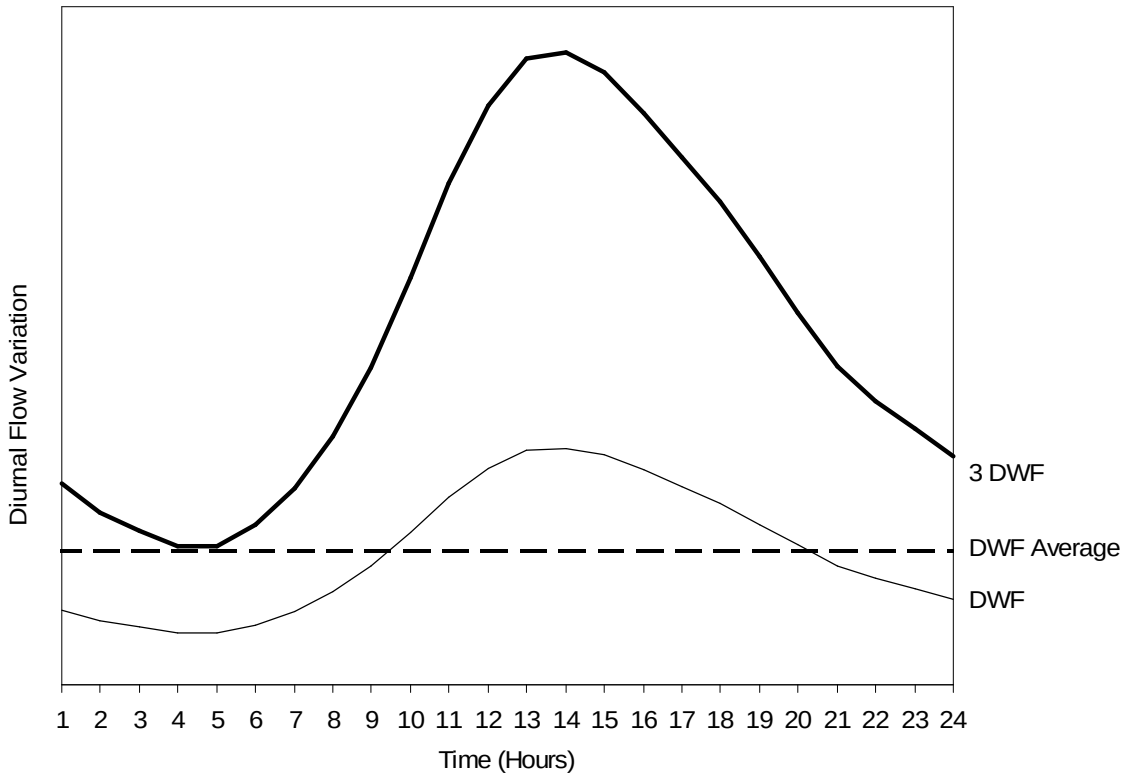


Fig. 4. Typical Diurnal Variation in Flow (Adapted from Nicoll 1988)

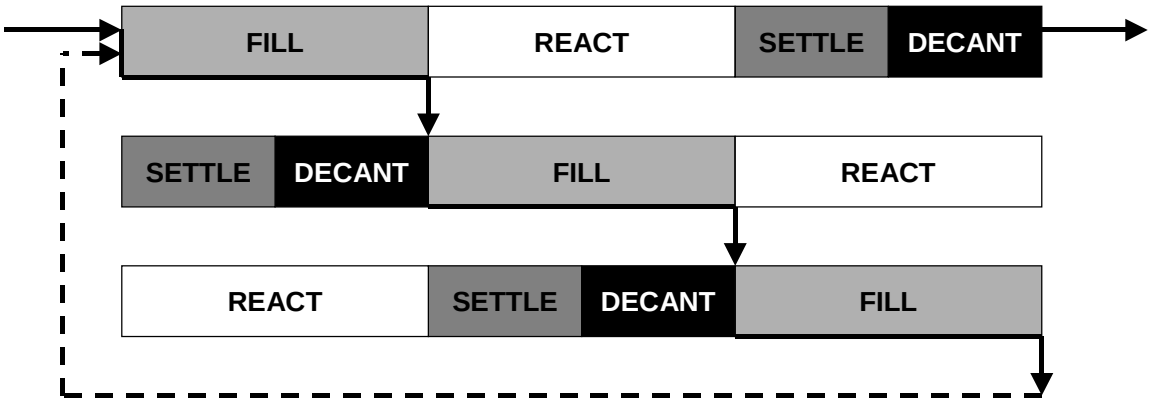


Fig. 5. Three Basin SBR Using Fixed Cycle Times

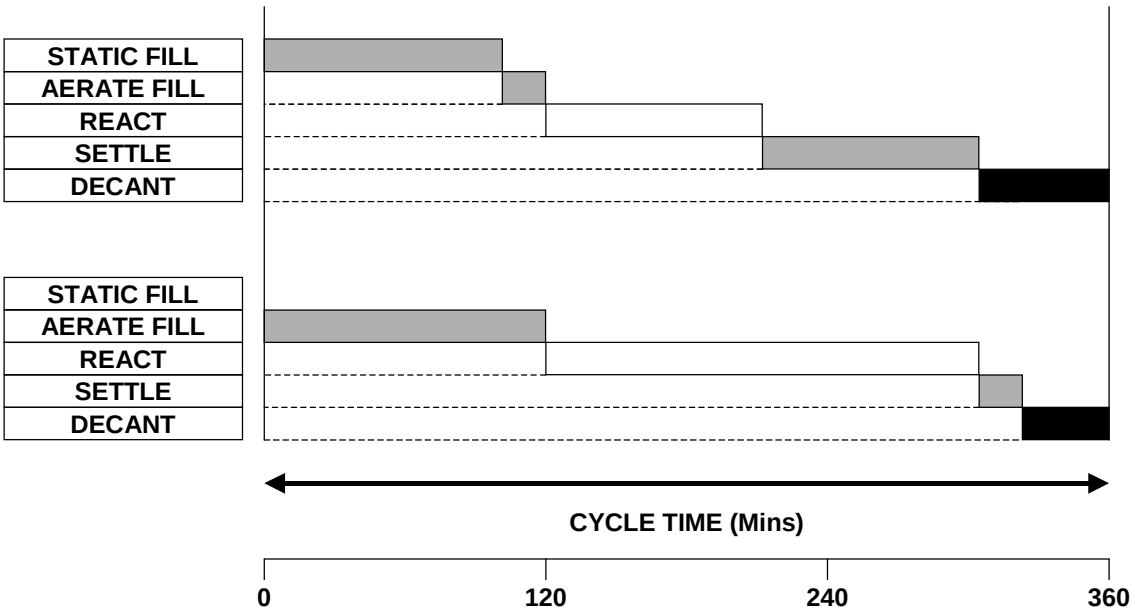


Fig. 6. Typical Three Basin SBR Cycle Ranges

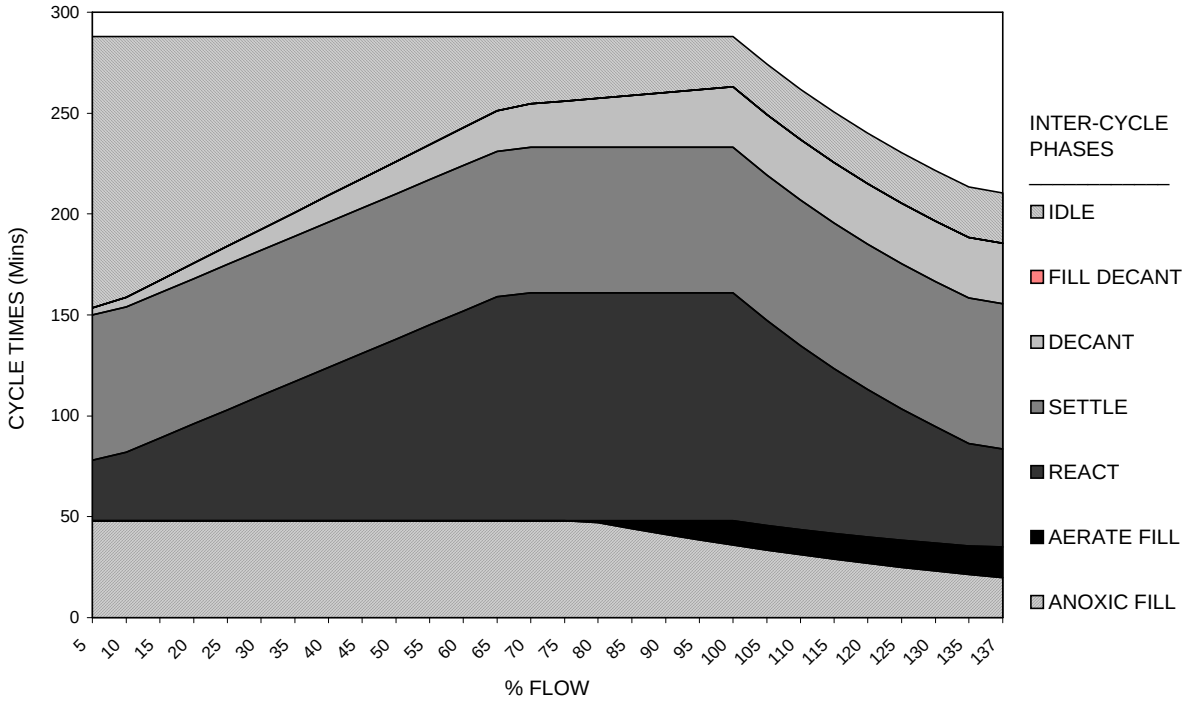


Fig. 7. Batch Proportional Operating Strategy

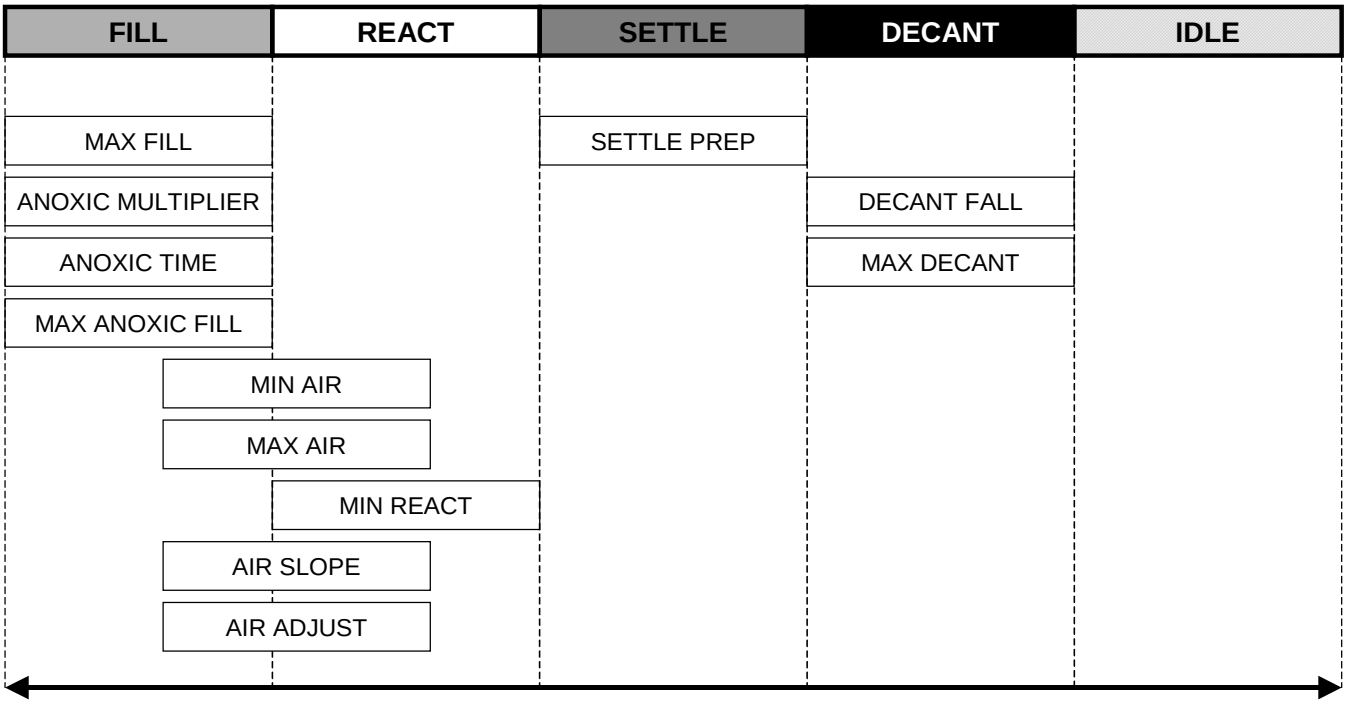


Fig. 8. Typical Process Set Points

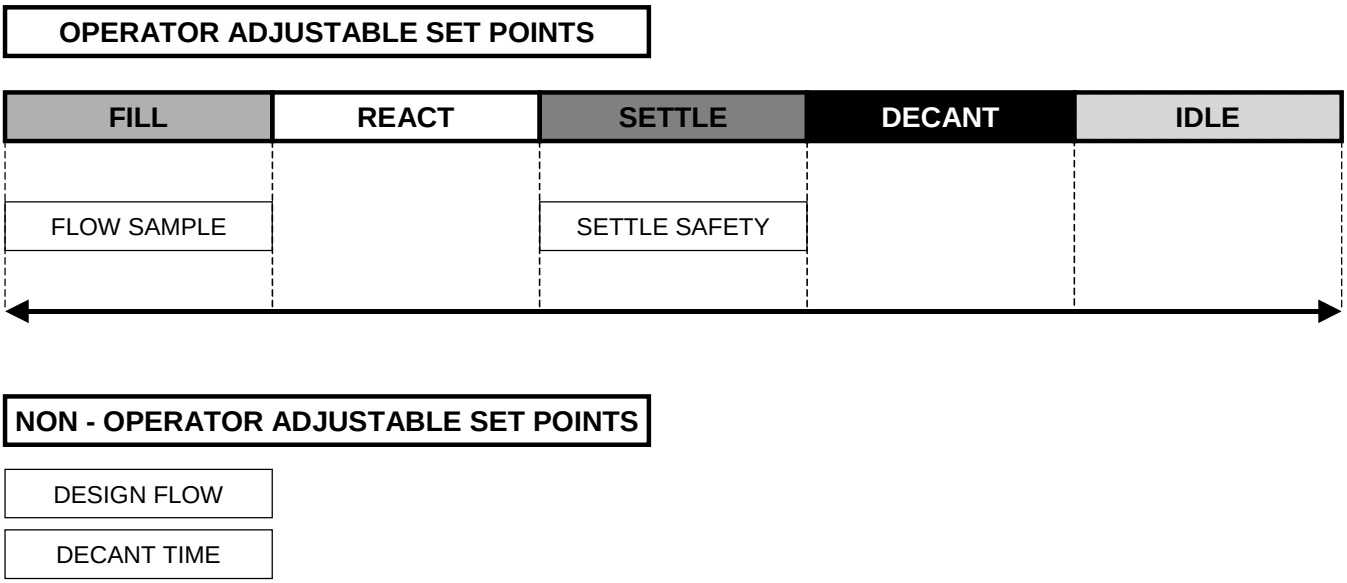


Fig. 9. Typical Hydraulic Set Points

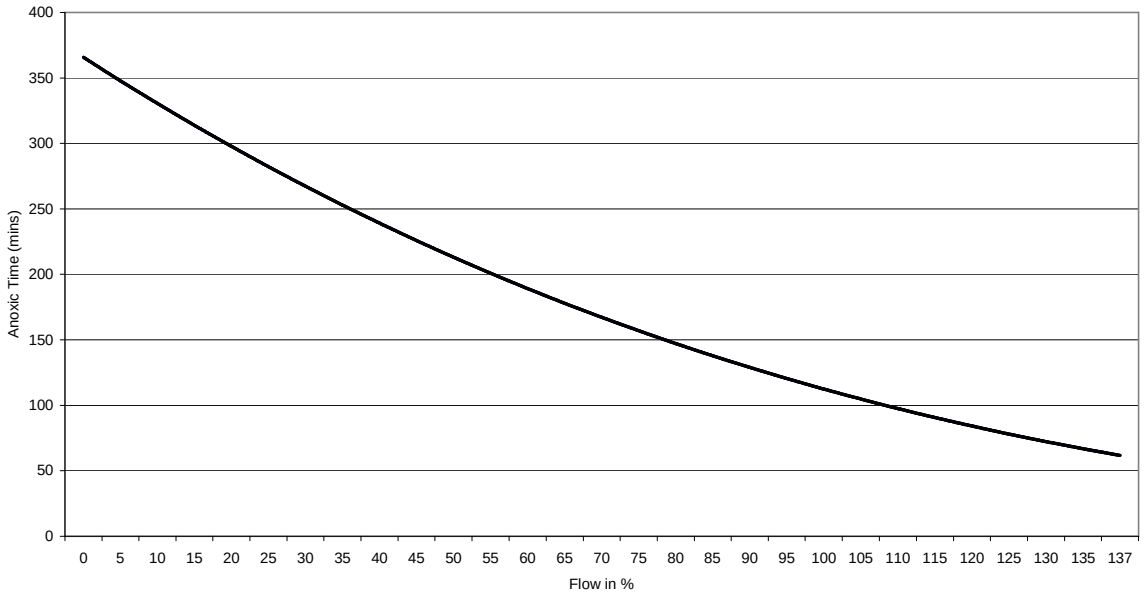


Fig. 10. Jet-Tech's Substrate Utilisation Curve

Table 1 - Water Level Calculation

Cycle No.	A HWL (m)	B Previous D (m)	C C = A – NHOL (m)	D D = (B-C) (m)
	Start = MDL			4.60
1	4.91	4.60	-0.29	4.60
2	4.84	4.60	-0.36	4.60
3	4.85	4.60	-0.35	4.60
4	4.97	4.60	-0.23	4.60
5	5.20	4.60	0.00	4.60
6	5.50	4.60	0.30	4.30
7	5.34	4.30	0.14	4.16
8	5.14	4.16	-0.06	4.22
9	5.06	4.22	-0.14	4.36
10	5.02	4.36	-0.18	4.54
11	5.11	4.54	-0.09	4.60
12	5.00	4.60	-0.20	4.60

HHWL= 5.7m (Fixed Value)
NHOL = 5.0m (Operator Adjustable Value)
MDL = 4.6m (Operator Adjustable Value)

1. Using Typical Diurnal Flow Variation Curve shown in Figure 4.
2. Convert flow rate to FILL batch time
3. Convert Feed Rate to Tank Wall Height (H)
4. Add H to D to give new HWL

Table 2 – Batch Timer Based Cycle Calculation

	DESIGN FLOW	**MAXIMUM FLOW**		
No. Basins	5	5		
Flow	100	140		%
Max Fill	60	43		mins
Cycle Time	5 x 60 = 300	5 x 43 = 215		mins
-	60	43	FILL	mins
-	75	75	SETTLE	mins
-	35	35	DECANT	mins
-	10	10	IDLE / WASTE	mins
=	120	52	REACT	mins
Max Air	114	114		mins
Aerate Fill	114 –120 = -6	114 – 52 = 62		mins
Anoxic Fill	60	43 - 62 = -19		mins

Table 3 – Process Based Cycle Calculation

	DESIGN FLOW	**MAXIMUM FLOW**		
No. Basins	5	5		
Flow	100	140		%
Max Fill	60	43		mins
Cycle Time	5 x 60 = 300	5 x 43 = 215		mins
-	60	43	FILL	mins
-	75	75	SETTLE	mins
-	35	35	DECANT	mins
-	10	10	IDLE / WASTE	mins
=	120	52	REACT	mins
Max Air	82	82		mins
Aerate Fill	82 - 120 = -38	82 - 52 =30		mins
Anoxic Fill	60	43 - 30 =13		mins

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Bungay, S.; Humphries, M.; Stephenson, Tom

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