Implementing batch digester control with a distributed control system

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Replacing an existing control system on a tight schedule can have its problems, challenges, and benefits.

Many pulp mills that originally installed supervisory control systems in the 1970s are now being forced to replace them. For one such mill in the Pacific Northwest, we have recently supplied a batch digester control package in a distributed control system. This package offered several improvements over their present system, including a flexible resource allocator, a powerful production scheduler, a cleaner operator interface, and an increase in control functionality of the batch operations. This paper offers a brief overview of the problems and challenges faced in the design and implementation phases of the project. It provides background information on supervisory control and the mill involved, then briefly describes the design of the production scheduler and resource allocators, batch operations, and man-machine interface.

Supervisory control

Supervisory control for batch digesting has become common practice in North America. A supervisory system was installed at the Consolidated-Bathurst mill in New Richmond, Que., in 1973 to increase pulp production capacity, improve kappa number and uniformity, improve pulp yield, and schedule the digesters (*1*). One was installed in 1977 at the Arkansas Kraft Corp. mill in Morrilton, Ark., to provide more uniform pulp by reducing the long-term kappa standard deviation, to increase pulp yield by raising kappa number, to reduce steam use per ton of pulp, to improve relief control, to obtain uniform charging, and to level out demand for the 160 psi steam (*2*). These represent typical objectives for most batch digester houses installing supervisory control systems in the 1970s.

Although most mills have been pleased with performance of their supervisory control systems over the years, these systems are now obsolete, with parts and support becoming increasingly difficult to find. Therefore, many mills are being forced to replace their present control systems. Since these systems have served well, many are content with their existing functionality. However, why duplicate existing functionality when it can be improved? To take advantage of current technology, these mills are looking to distributed control system suppliers for possible solutions. On this project, we worked as a team with a mill to design and implement a distributed control system to overcome some of their existing supervisory system's shortcomings.

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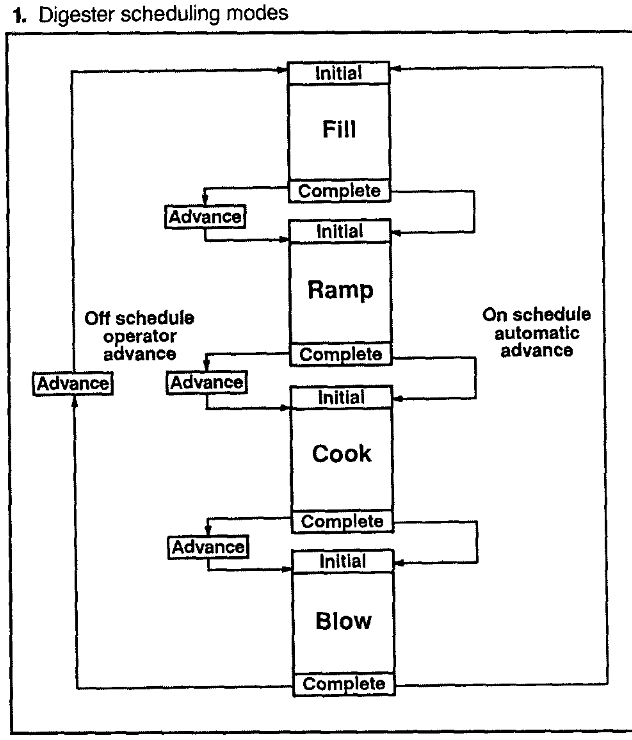
1. Digester scheduling modes



Project background

This digester house, located in the Pacific Northwest of the United States, is already at maximum production. A supervisory control system installed in the mid-1970s provides all process control and event sequencing of the twelve digesters. A programmable logic controller handles safety interlocking and motor start/stops and interfaces with the supervisory system. A panel board with single loop controllers from another supplier is responsible for the auxiliary house controls.

The mill was pleased with the performance of the supervisory system; however, parts and service support were becoming nonexistent or expensive. These factors, coupled with the need to move ahead in distributed control for millwide system integration, led the mill to examine the idea of replacing the existing digester house control system with a new distributed control system.

The mill wanted a flexible, adaptive control system whose design would easily allow for future changes in process equipment, product grades, or operating philosophy. Additional project objectives included a simplified operator interface for the batch operations; an efficient transfer of information between the continuous, common areas and the batch, operation areas of the control; and an enforcement of strict sequencing with flexible means of circumventing the schedule for adapting to operational problems.

There were also several constraints. One was the fast-track schedule for replacing the existing equipment: it required customer acceptance of the control system only five months after the project was awarded. Since the mill is digester-house limited, loss of production was another area of concern. They had therefore timed startup of the new digester house system to coincide with a mill outage for a new paper machine installation. Other objectives and interesting challenges included training mill personnel on features of the new control system; enforcing a maximum production schedule while maintaining quality; and designing flexible utilization of the limiting, common resources.

Production scheduler and resource allocators

The production scheduler is designed to calculate house cooking temperatures and cycle times and to allocate common house resources (liquor header, chip conveyors, and blow header/tank) according to a strict fill-and-blow sequence for the twelve digesters. Three separate resource allocators (chip fill, liquor header, and blow tank) and a production scheduler calculation are designed based on actual conditions and overall operating objectives. The operator enters a production rate, and the scheduler then calculates target times and temperatures needed to achieve that rate based on current operating conditions. The resource allocators can handle the strict sequence and still allow the operator to bypass digesters easily.

Resource allocation

The existing supervisory control system had two modes of operation for each digester: it was either "on-line" or "off-line." This made it difficult to take a digester down for maintenance because the operator had to set the digester off-line right after it finished blowing. To increase flexibility and overcome this problem, the new system has a software switch with three modes of operation: "on-schedule," "off-schedule," and "off-line."

An on-schedule digester is completely automatic as far as the scheduler and allocators are concerned. In this mode, the digester is considered for all resources and is automatically advanced between the operations (fill, ramp, cook, and blow). Although an off-schedule digester is considered for the common resources, it can be skipped for chip and liquor fill resources depending on conditions. Off-schedule digesters have to be advanced between operations, as shown in **Fig. 1**. The off-schedule mode is used for digester check-out, startup, reject cooks, and preparing for a digester shutdown. All on/off-schedule digesters are used for production calculations and considered "on-line." Last, any off-line digester, down for maintenance, is not considered for the common resources and is not used in the production calculation.

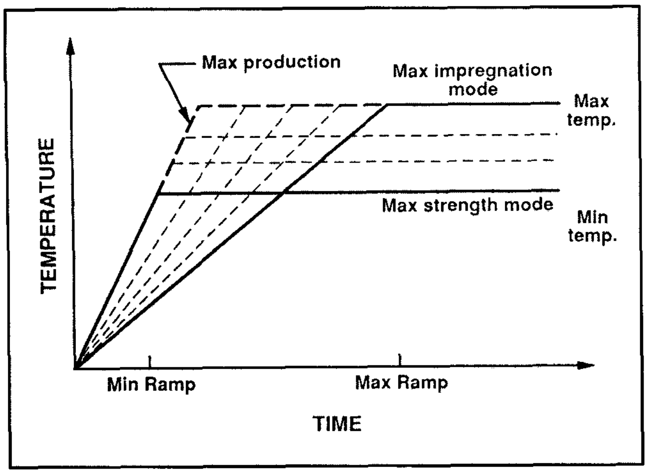
As mentioned earlier, there are three different resource allocators in this system: chip fill, liquor fill, and blow tank. Each works independently to determine which digester is next for the chip feed system, liquor feed system, or the blow tank. The blow tank allocator will work on a strict sequence for all on/off-schedule digesters. The chip and liquor allocators also work off a sequence; however, they can also automatically bypass an off-schedule digester. If a given digester is off-schedule, not ready for the resource, and the resource is available, then the next on/off-schedule digester in sequence can get the resource if it is ready to fill. Once a digester has acquired the chip fill resource, it becomes the next digester for the liquor fill resource. To save time in the fill operation, the tripper car of the chip feed system will be pre-positioned over the next digester.

If the operator needs to fill or blow a digester out of sequence, both "bypass-fill" and "bypass-blow" software switches are provided. These switches have individual setpoints for each digester. For example, if the operator wants to chip and liquor fill digester No. 1 out of sequence, he selects the bypass-fill switch and sets the setpoint to "fill 1." Once this digester has been filled, the scheduler will then set it back to automatic. The same is true for the bypass-blow switch.

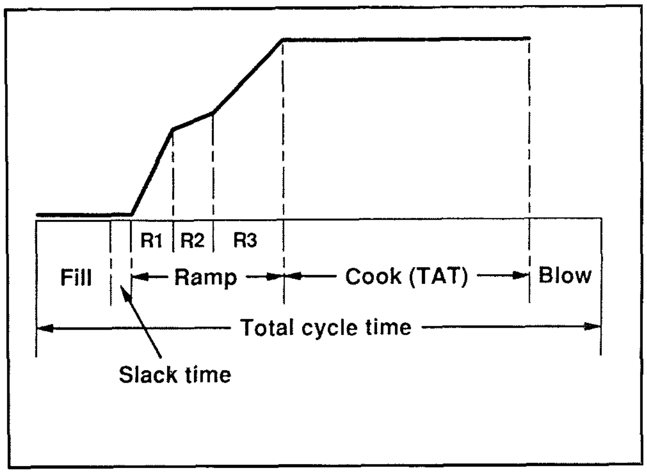
Production calculation

In addition to the resource allocators, another function of the production scheduler is production calculation. This function calculates the house targets for cook temperature, ramp time, cook time, idle time, total cycle time, and current production rate. It determines the number of on-line digesters, reads the entered target production rate, and calculates the total cycle time. It then subtracts the average "learned" fill and blow times on those digesters to get available ramp and cook time. Using a target *H*-factor, which is calculated from an entered kappa number target, it calculates the cook time required. The resultant ramp time is then multiplied by a tunable "rise to temp ratio" and limited to get the target ramp time. This ratio can be tuned for quality improvements. **Figure 2** depicts the various curves that the ratio can produce. The cook time is calculated and used to back-calculate the cook temperature. The temperature is then limit checked and used as the house target cook temperature. All these values are passed as house targets to the other controllers over the data highway.

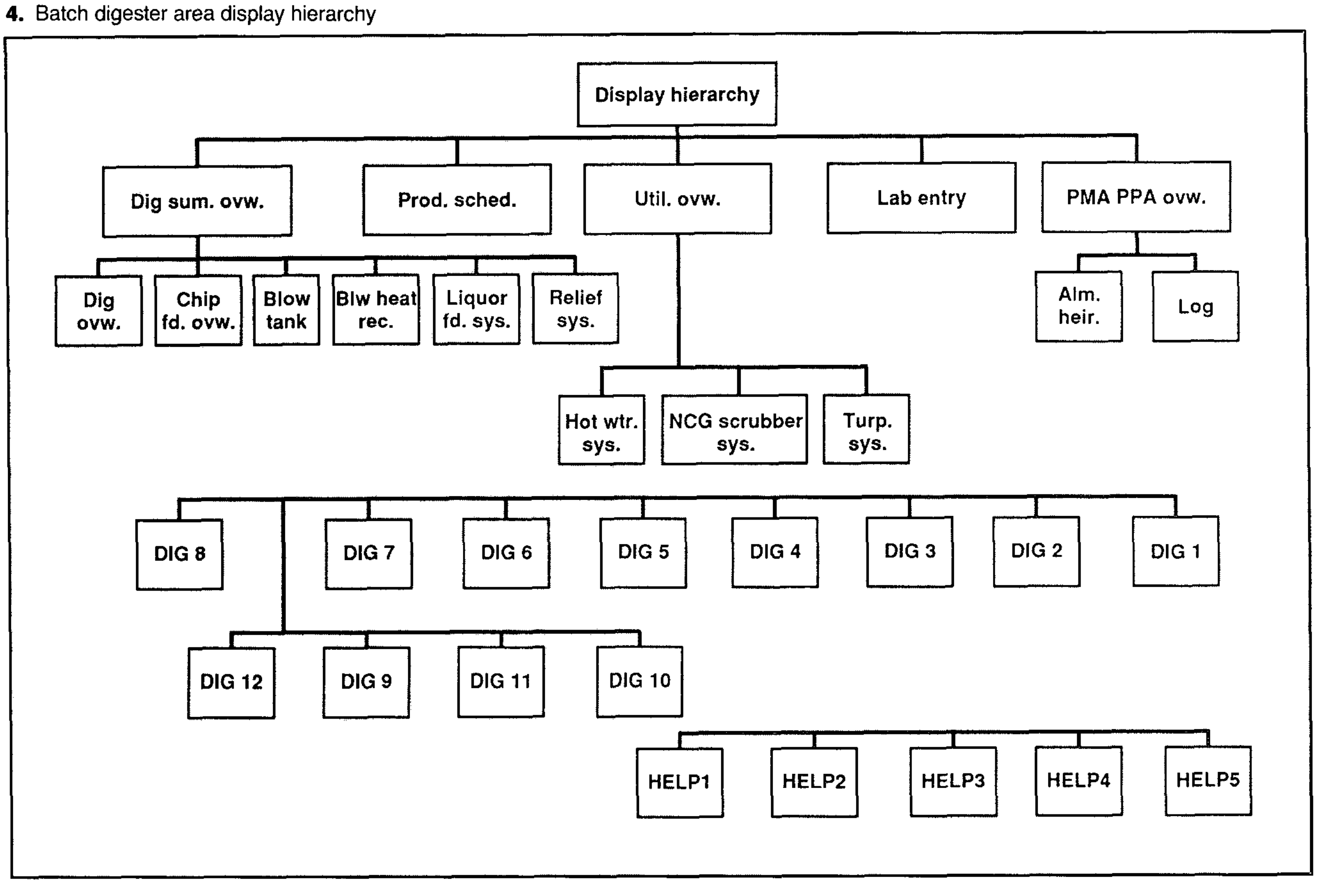
2. Rise to temperature curves



3. Digester operations



4. Batch digester area display hierarchy



Batch operations

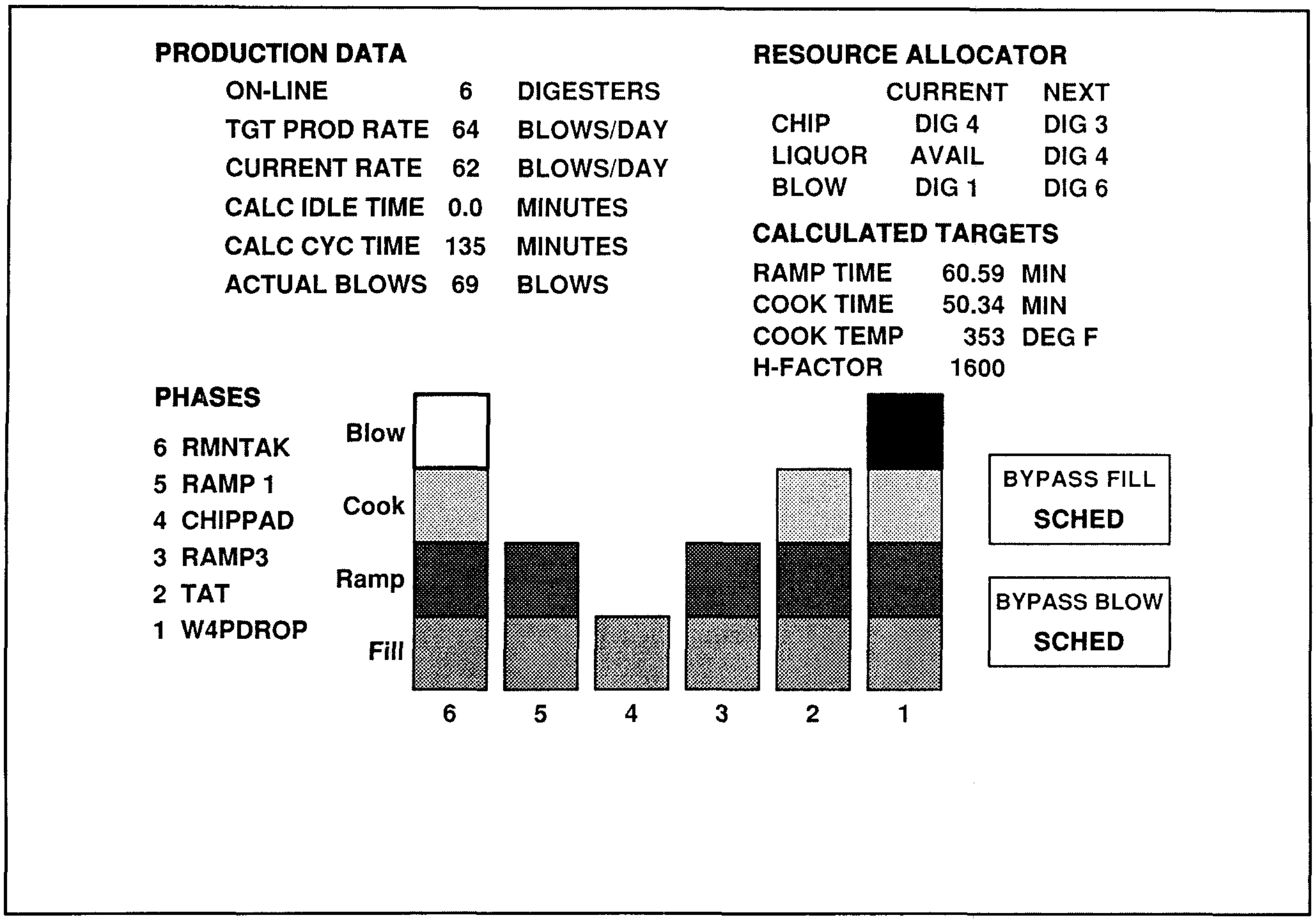
The batch digester control cycle is divided into four operational states: fill, ramp, cook, and blow. These states with the calculated slack time make up the entire cook cycle, as shown in **Fig. 3.**

Chip and liquor fill

The fill operation coordinates the common house resources required to add wood chips and liquors to the digester. The operation reads the appropriate information from the grade data tables and makes the necessary calculations for charging. Once the initial charge targets have been calculated and the requested common resources acquired, the operation proceeds with the predetermined order of events for charging the chips, rejects, black, and white liquors. After the initial charge of liquors and all of the chips have been loaded, the remaining top-off liquor volumes are calculated and charged into the digester. The fill operation ends when all targets are met, resources are released, and the cap valve is closed.

Regulating white and weak (black and rejects) liquors to achieve target alkali/wood and liquid/wood ratios is essential for maintaining consistent quality and minim-

5. Production scheduler display



izing overall chemical costs. The key to this is in the liquor calculations. The more accurate the data used by the calculations, the more accurate the amount of liquor applied per batch. Initial liquor calculations are based on the last batch chip charge of the individual digester, and final charge calculations are based on the current batch chip charge. Percent moisture used in the calculations can be derived from an on-line moisture signal (not in place at this mill yet), from an assumed moisture from lab samples, or from a calculated moisture based on last-batch information. Condensate from steam used in cooking is also compensated for in the total weak (black and rejects) liquor calculation. Condensate is based on the average learned value of pounds of steam per cook. All targets are high-limit and low-limit checked for validity.

For each digester, the operator can choose from two methods for determining the end of chip fill: target volume and a nuclear level switch. If the nuclear level switch is used, a check is first made to ensure that integrated chip volume is within a target range. If insufficient volume exists, a warning message is displayed, and the operator must give the "OK-TO-GO" for the operation to proceed after the problem is corrected.

Ramp to temperature

The ramp operation is divided into three main phases to facilitate bringing the digester up to cooking temperature in the most efficient manner while providing the means to incorporate steam allocation. The total time in ramp is calculated by the production scheduler. The time spent in any of the ramp phases is a tunable percentage of the total. The amount of work (steam applied) to be done in each of these phases is adjustable on an individual digester basis. These factors are used in an adaptive calculation of the steam needed to raise the temperature a given amount during the first two phases of ramp. This calculation is continuously performed by the steam allocator when the digester is ramping.

This calculation is used to open the steam valve to a specified position in the first two phases of ramp, when temperature is the least reliable. The third phase of ramp, when the temperature should be relatively stable and reliable, functions in a continuous feedback mode with the temperature and steam control loops. However, for additional flexibility and security, a weighted average of the upper and lower measurement probes are used for temperature control. Operational control limits are imposed in all phases.

The primary objective of the excess pressure control is to allow the digester to vent entrained air, distilled resins, and noncondensable gases in the early stages of steaming while maximizing the turpentine recovery. A second objective is to obtain the correct relationship between temperature and pressure during the cook operation. The control is designed to modulate the position of the relief valve so digester relief is proportional to the rate at which

6. Digester summary graphic

	6	5	4	3	2	1
OPERATION	BLOW	RAMP	FILL	RAMP	COOK	BLOW
STEP #	4	3	3	5	2	6
TIME IN OP	2	10	5	54	35	8
TIME IN CYCLE	135	21	5	70	105	130
TIME TIL BLOW	0	120	130	60	30	0
SCHEDULER	ON-SC	ON-SC	ON-SC	OFF-SC	ON-SC	ON-SC
PHASES						
ACTUAL	1155	1158	0	1155	1163	1167
TARGET	1150	1150	1150	1150	1150	1150
WHITE LIQUOR						
ACTUAL	1155	1158	0	1155	1163	1167
TARGET	1150	1150	1150	1150	1150	1150
REJECT LIQUOR						
ACTUAL	761	765	0	760	758	763
TARGET	750	750	750	750	750	750
BLACK LIQUOR						
ACTUAL	55	55	0	55	55	55
TARGET	50	50	50	50	50	50
TOTAL LIQUOR						
CHIP WEIGHT	1971	1978	0	1970	1976	1985
ACTUAL	39	40	0	41	40	44
TARGET	40	40	40	40	40	40
ACTUAL OD TONS	22	23	22	22	22	25
K-RAY	FULL	FULL	OFF	FULL	FULL	FULL
PRESSURE	110.7	99.6	110.0	109.5	112.2	110.0
AVG TEMP	348.5	336.0	353.0	352.0	351.4	347.6
H-FACTOR						
ACTUAL	1620	0.0	1602	105	975	1602
TARGET	1600	1600	1600	1600	1600	1600

noncondensable gases are generated. The strategy for manipulation of relief and blowback valves is changed as ramp and cook progresses in order to obtain the best relationship between temperature and pressure in all phases.

Cook or time at temperature

Pulp quality is very dependent upon the time-temperature profile used during a cook. The reaction rate at which delignification occurs is exponentially related to temperature. Therefore, temperature variations during a cook will have a direct influence on yield and kappa number. For these reasons, Varoom's *H*-factor model is used, which combines the time/temperature relationship into a single variable (*3*). Although time and temperature may vary during a cook, consistent *H*-factors can be achieved.

During the daily operation of a digester house, several things can occur to upset the cooking cycle and the schedule. Two different controls are provided that allow the operator to interact with the cook operation directly.

One control provided is called overcook. This control becomes active only after being selected by the operator. When activated, the control automatically begins a procedure that slows down the heat of reaction in the digester. The steam valve closes while the relief opens to a specified target. Temperature and pressure decrease, causing the heat of reaction to slow. When the operator removes the overcook, the digester automatically returns to normal cooking conditions.

The other control, active during the entire cook cycle, overrides the current cook conditions only when the operator intervenes and acknowledges the control request. This control continuously runs a calculation to determine where the batch is in the cycle and where it will be if current conditions stay the same. If the batch is not maintaining the current production schedule, a new cook temperature setpoint is calculated that allows the operation to complete on time. This calculation will select a higher temperature value if the batch is behind schedule and a lower one if the batch is ahead of schedule, always maintaining target *H*-factor. The operator is then given the opportunity to accept or reject the new temperature setpoint. If the operator does not respond, the request will time out and a new setpoint will be calculated under the current conditions of time, temperature, and *H*-factor. This cycle continues until the cook is within the time calculated for blow permit to be activated. High and low limit checks are made in all calculations for verification of the new target setpoints.

Blow

When the cook operation has been completed and the digester is advanced into blow, several conditions are verified before the blow valve is opened:

- Is this the next digester scheduled to blow?

- Is there sufficient room in the blow tank?
- Is any other digester blowing?
- Has the cook accumulated the required *H*-factor?
- Is the digester pressure above the minimum blow pressure?
- Has permission to blow been given?

Permission to blow can be given in two ways: either the operator acknowledges the request displayed on the console, or the operation automatically answers the request. The operation will answer the request if a software switch called "autoblow" is set to yes. Once all conditions are met, the blow valve is opened. When the pressure drops to below 2 psig, blow is considered complete. The blow valve is closed and the cap valve is opened, which leaves the digester ready to be filled.

If the operator decides the batch needs a boost during the blow operation, he can select a software switch that enables a blowback during the early stages of the blow operation. If this control is activated, a blowback will be triggered at approximately 100 psig.

Man-machine interface

The operator interface starts with a help screen, which shows the display hierarchy of the digester house and the common area, as illustrated in **Fig. 4.** This display depicts the relationships between "pages" of graphic displays and allows the operator to page forward, page back, page up, and page down to select a display and go directly to it. Each process graphic display has five touch-screen keys. These keys, when touched by the operator, provide easy access to a motor faceplate page, a control faceplate page, a trend page, a help page, or another graphic display.

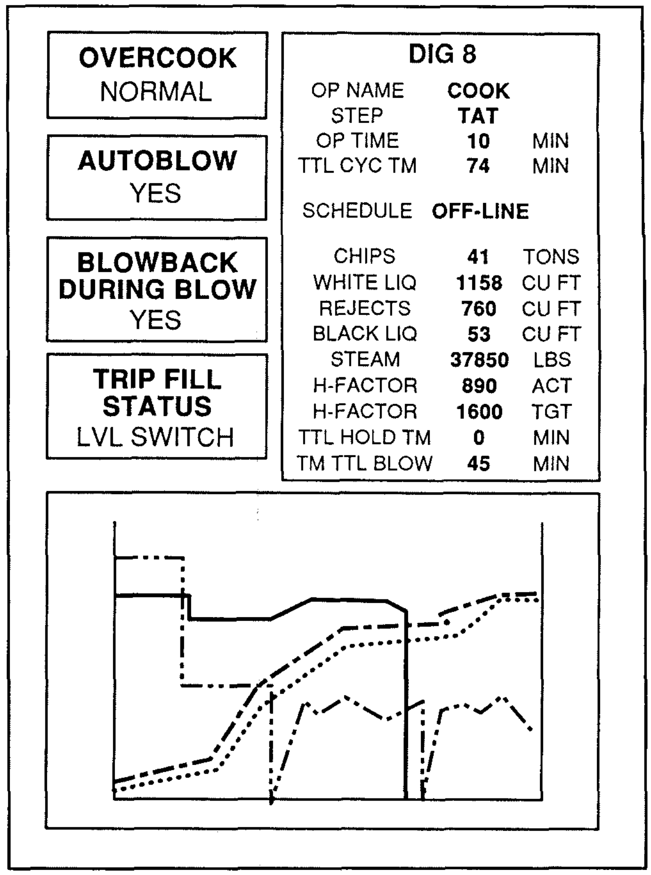
Overview screens allow the operator to monitor the entire house and operate the production scheduler functions. From the production scheduler display, shown in **Fig. 5,** the operator can view and set the operational mode of the digester (on-schedule, off-schedule, or off-line). A multicolored bargraph identifies the operation and phase each digester is in. This is also the display the operator uses to enter the production rate target. The digester summary display, shown in **Fig. 6,** includes fill parameters for the current batch in each digester. This display also shows pertinent operation times (cycle, operation, blow) with the current operation running for each digester.

Besides the two overview displays, each digester has a display showing detailed information about that digester, as illustrated in **Fig. 7.** Here the operator can see the steam flow, top and bottom temperatures, target temperatures and times, current time in an operation, and detailed batch information. The operator also has available a trend window for tracking temperatures, pressure, and *H*-factor with a graphic representation of the digester on each individual display.

Results and conclusions

This project is currently on schedule. The control package has already been simulated for customer acceptance and operator training. Simulation has also supplied an excellent means of tuning and debugging the system before startup. The mill is looking forward to gaining the added functionality over their present system—including the flexible resource allocators, scheduler, operator interface, and batch operations—and getting these benefits in a redundant distributed control system that is consistent with their millwide strategy.□

7. Individual digester graphic information



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