Unit-4

Process control Applications: Building conditioning control: Fan control and temperature control, batch control description and terminology: Batch Automation, Product Management, safety interlocking, Boiler control: role of sensors, safety interlocking, and wastewater treatment control: two reagent control system, steam turbine controls: controls and optimization.

Batch Automation:

Automation of batch production is composed of three functional levels:

1. **Batch planning:**
   The sequence of production is planned and scheduled with available resources, including raw materials, personnel, and equipment.
2. **Batch control:**
   Production flows and production steps are described. Recipes are processed and executed in this level.
3. **Real-time monitoring and control:**
   Basic equipment control is performed at this level. This classical process automation includes safety interlocking input/output processing, and discrete control.

The control activities of an entire batch control system are in Table 8.3b.

TABLE 8.3b
Control Activity Model

Level	*Function*	*Activity*
Planning	Process/product management	Production planning, inventory planning, general recipe management, etc.
	Production management	Recipe management, production scheduling, batch history management, etc.
Batch control	Batch management	Recipe generation/selection, batch execution supervision, unit activities coordination, log and report generation, etc.
	Unit supervision	Unit allocation management, unit coordination, etc.
Monitoring and control	Process control	Sequential/regulatory/discrete control: device, loop, and equipment module control, predictive control, model-based control, process interlocking, etc.
	Safety interlocking	—

Batch planning activities involve process/product management, production/batch management and production planning and scheduling, batch control activities involve batch management and unit supervision, and basic equipment control activities involving sequential/regulatory/discrete control of physical control devices, such as sensors and actuators, and safety inter-routine sequential, regulatory, and locking.

Process/Product Management:

Process/product management is the highest level of control activity. Corporate planning for the business is made and is linked to the various operating units. Activities like material and resource planning (MRP), inventory planning, and accounting is done.

Process/product management is an activity accepts inputs, such as customer orders, and based upon a manufacturing strategy develops a production plan.

The production plan includes:

1. What is to be produced?
2. How much is to be produced?
3. When is it needed?
4. Where is it to be produced?
5. How is it to be packaged?

The output of the production plan becomes an input to the production schedule of the individual plant.

Production Management

Production management is made up of three control activities:

1. Recipe management,
2. Production scheduling, and
3. Batch history management.

Recipe Management:

A recipe is the complete set of data and operations that define the control requirements of a particular type or grade of product.

A recipe is composed of types of information:

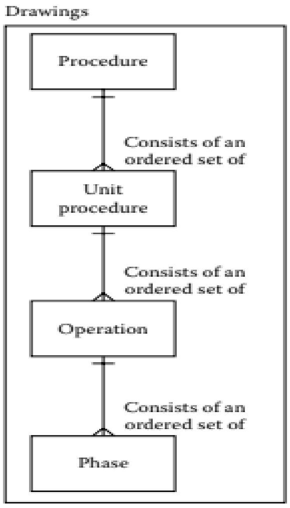
(1) **Header:** Headers provide information about the source and version of the recipes, such as recipe and product identification, author, issue, and date and any other pertinent batch information such as MSDS or hazard or toxicity issues specific to the product or processing activities and the like.

(2) **Equipment requirements**: Equipment requirements specify the type and size of equipment needed, such as glass lining required and 20,000-liter vessel required.

(3) **Formula**: Formulas are sets of parameters, such as types and quantities of ingredients, durations, and process condition set points, that distinguish the products defined by procedures and

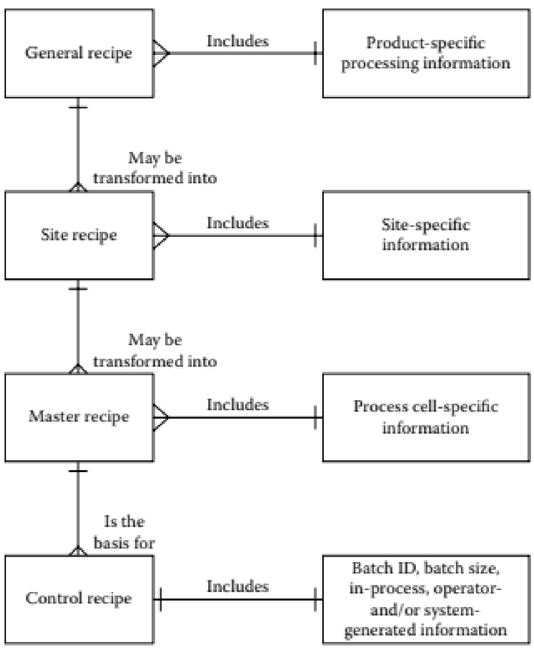
(4) **Procedure**: Procedures define and order the actions to be performed and the associated control requirements necessary for making a class of products in the batch process. The procedure defines the generic strategy for producing a batch product and is made up of unit procedures.

Procedural model: Fig.8.3c



Unit procedures are an ordered set of operations that causes a continuous production sequence to occur in a unit. An operation is an ordered set of phases that defines a major processing sequence. And operations are made up of phases that accomplish a process-oriented task. Phases may include the control steps or control instructions that execute the base- level control. The relationship is diagrammed in Figure 8.3c.

Recipe model: Figure 8.3d.1



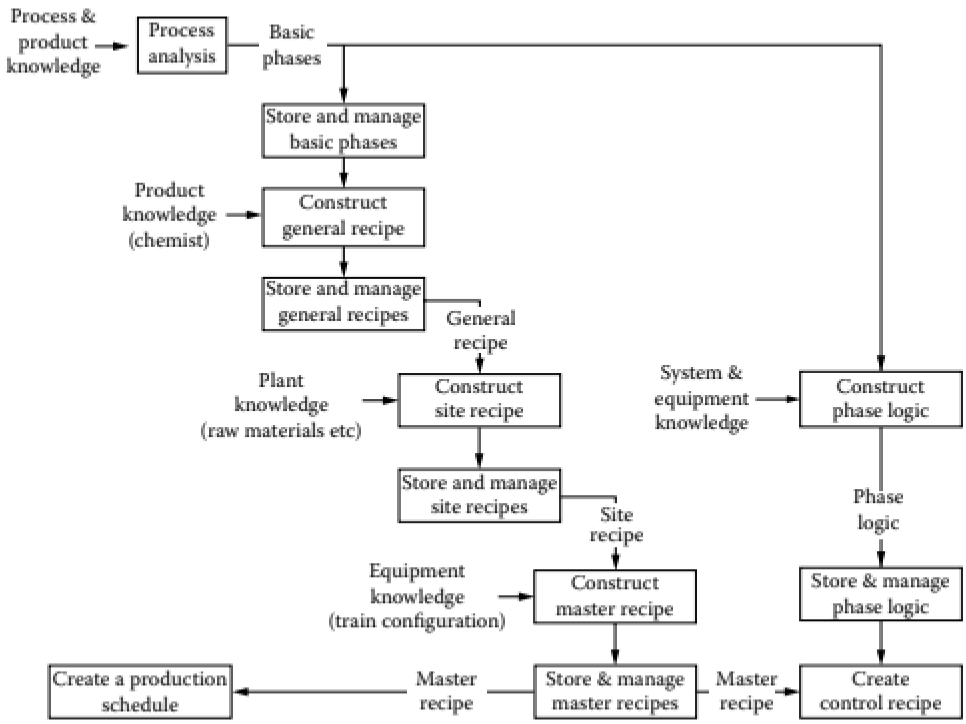
The actual executable logic of the control is linked via the recipe information to a particular unit where the unit recipes, operations, or phases are run in the order determined by the recipe.

In the current generation of control systems, the recipe management function maintains a set of master recipes for various products and families of products. Specific information of the batch equipment and units that can run each operation within the procedure are contained within the control recipe.

A master recipe is constructed from the site recipe using the formulas, procedures, and equipment-specific information. The master recipe is selected and accessed by the batch management activity, which converts it to a control recipe. This control recipe is the batch-specific recipe that is ready to run.

Utilizing process and product knowledge, a process analysis is performed and basic phases are determined. These basic phases, along with product knowledge from the laboratory chemist, are used to construct the general (corporate-wide) recipe. Plant knowledge (for example, raw material availability) from the plant site engineer is used to transform the general recipe to a site-specific recipe. Equipment knowledge (for example, what vessels and piping are available at the plant) is used to transform this site recipe into a master recipe. This master recipe is used as the basis for a control recipe when a batch is ready to be produced.

The activities involved during recipe management are summarized in Figure 8.3e.



Production Scheduling:

Schedules serve as guides for production requirements in terms of availability of equipment, personnel, raw materials, facilities, equipment, and process capacity.

The objectives of Schedule:

1. Minimize the processing time

2. Minimize the deviation from a master production plan

3. Optimize the production of products within quality guidelines

4. Minimize energy costs

5. Minimize the usage of raw materials

6. Minimize rerun

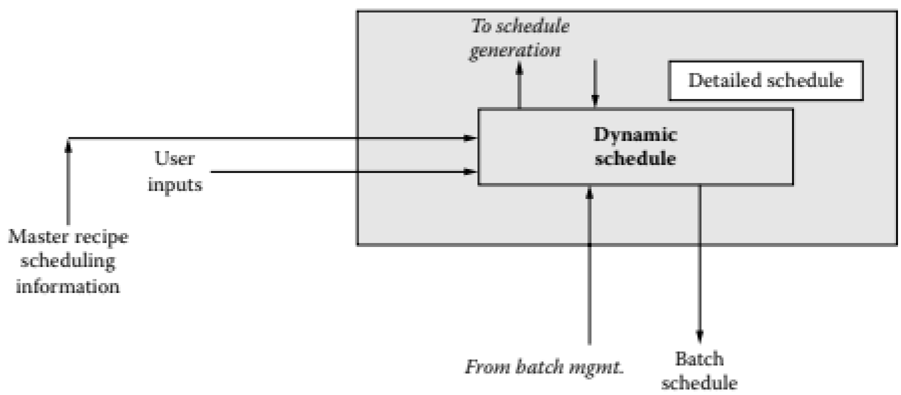
Production scheduling accepts inputs such as the production plan and based upon a scheduling activity develops a production schedule that typically specifies batches/amounts to be produced, target trains/lines to be used, time targets, product dispositions, and resource constraints.

The master production schedule answers what to schedule, when to schedule, and how much to schedule. The production schedule further reduces the production plan, which was developed in the company management layer (process/production management) and directly drives the production of individual batches.

The responsibility of the production scheduler is to develop a detailed time-based plan of activities to achieve the production targets set by the production plan. It needs to dynamically allocate a new schedule at any time. It should be feasible to reallocate or create a schedule automatically via some algorithm or manually via user intervention.

Schedulers can be implemented via any number of ways: Linear programs, expert systems, or other multivariable techniques have been used. The scheduler needs to provide a procedure or method for batch sizing and is the logical place where lot or even batch ID assignments are made.

Production scheduling model:



As shown by the model, a dynamic scheduler accepts user inputs, master recipe information, and updates from process management to develop a batch or production schedule.

The dynamic scheduler must be able to:

1. Organize a new schedule at any time

2. Provide for interactive scheduling
3. Allow for manual intervention
4. Determine the availability of resources
5. Provide for a method to carry out the schedule
6. Provide a procedure or method for the lot sizing along with a means to organize autonomous orders with this lot size
7. Determine the feasibility of the schedule
8. Information about times and availability of resources are key inputs to the scheduler. Because the basic data about the unit operations, master recipes, key times, resources, quantities, priority, and orders and their operations are required, it seems reasonable to conclude that the dynamic scheduler is a real-time activity.

The dynamic scheduler requires non-real-time data from production planning and recipe management as well as real-time feedback data from the batch manager and lower-level control activities. The dynamic scheduler can contain some kind of optimizing capability.

Batch management provides the updates of information to the scheduler in real time and also provides the status of material and equipment. The user needs to be advised of the schedule situation continuously. Thus, reporting and status information are important. Information provided to the user can include the control recipe, the lot number, the product being produced, the amount being produced, the train/line being used, the status of the recipe, the mode of operation, priority, start times, and end times. The mode of the lot in the queue determines whether the recipe is to start automatically, semi automatically, or manually. In the manual mode, stepping through the batch sequence is done by the plant operator via specific commands.

In semiautomatic mode, the batch sequence is initiated by the operator and requires operator intervention when proceeding from one phase or operation to another. In the automatic mode, once the sequence is initiated, it can be repeated a predetermined number of times without any operator intervention. The mode of the batches in the queue also determines whether any information in the queue is operator alterable, and whether the control recipe has been bumped or interrupted by another control recipe of higher priority.

Batch History Management:

Batch history management has the following main functions:

1. Receiving and storing information from other parts of the overall batch control system on the individual batches
2. Producing output information from single batches, from several batches, or as an overview of multiple batches
3. Producing batch reports on the basis of output information
4. Maintaining production records and batch history archive by supporting data reduction, backup, and deletion features

Although many data logging and reporting techniques for batch processes are similar to those for continuous systems, production records have some significant requirements that may be different. Two needs are batch tracking (some may use the term lot tracking) and the batch end report.
A batch historian must collect and maintain integrated, identifiable sets of dissimilar data.

Batch tracking is the collection of this data and is generally event-triggered and typically contains the following related data:

Continuous process data (flows, temperatures, and pressures)
Event data (operator actions, alarms, notes)
Quality data (lab analysis, inspection notes)
Recipe formula data (quantities desired and used, set points, times)
Calculated data (totalizations, material usage, accounting data)
Manual entries with audit trail (location of change, operator of record)
Stage, batch, lot identification
Time/date stamps on all data

A **batch end report** may typically include a copy of the master and/or control recipe that was used to make the batch. This may not be identical to the original recipe because of operator modifications, equipment problems, and so on.

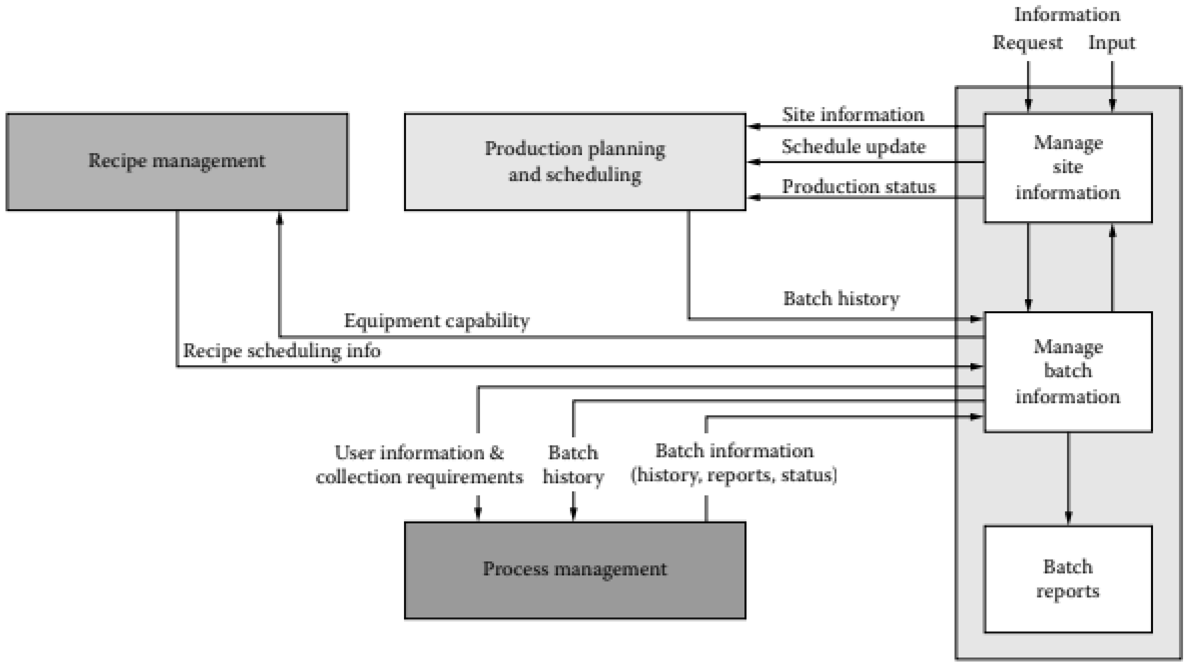
Events such as alarms, operator instructions, and equipment status changes should also be logged. This log can be designed so that it will retain the total operational sequence chronologically with date and time.

A trend chart can also be retained. A recipe expresses the desired approach by which a batch is to be made, while the batch report provides a record of how the batch was actually made.

Batch management takes care of the recording and collecting of batch end reports, which are then archived to some other medium.

Batch reports are a statutory requirement in some applications (for example, in the pharmaceutical industry); however, because the information is so valuable, it is being demanded in many other batch applications.

A simplified batch history management model :

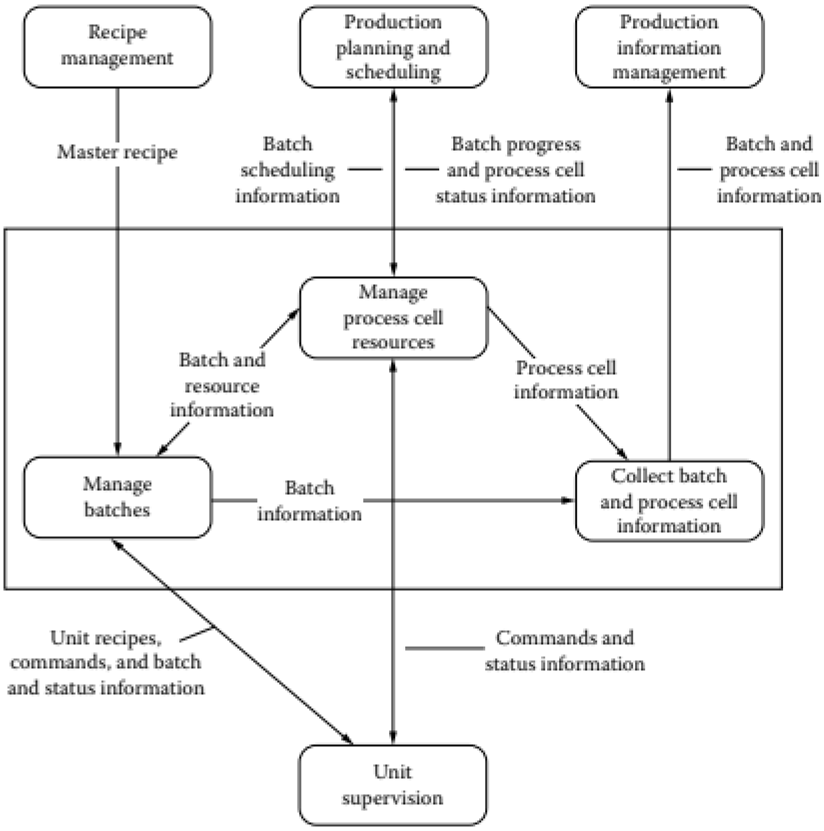


Batch history management is an activity that is not bound to the actual execution time of the batches and not bound to the equipment on which the batches are produced. It involves the process of sorting out the production records and batch end reports, because even a perfect batch may be undeliverable without batch records. Advances in relational databases allow the bridging of data between the process control of current batches and the histories of previous batches. The ability to use standard query language (SQL)-like calls to access batch history allows new avenues to analyze and report batch histories. Other analysis techniques, such as statistical process control and statistical quality control (SPC and SQC), can be applied at this level.

Batch Management

Batch management interfaces with the user, recipe management, production scheduling, unit management, sequential control, and regulatory and discrete control in performing its functions of
(1) recipe selection, transformation, and editing to manage batches;
(2) initiation and supervision of batch processes;
(3) management of batch resources; and
(4) acquisition and management of batch information.

A batch management model :



Batch management includes basic functions to managing batches by using control recipe information, batch information, and equipment information to:

1. Select a master recipe from recipe management and transform it to a control recipe that can be used to run a batch
2. Assign a batch identification code

3. Time-stamp the control recipe when the batch identification is entered
4. Verify the information in a control recipe, such as its completeness and its ability to execute on the selected units
5. Maintain the control recipe until the batch is completed

Additionally, the batch management function:
1. Initiates control recipe execution based on time or event
2. Assigns and releases units, and updates their status
3. Distributes the parts of the control recipe to unit supervision
4. Starts the batch based upon start conditions and the detailed schedule, whether upon event or time
5. Regulates the distribution of operation or phases for execution
6. Reports and time-stamps events for information management
7. Allows users to alter normal processing
8. Maintains batch status information
9. Allows batch to be suspended, removed, and later recalled

Managing batch resources takes the detail schedule and master/control recipe information and provides for:
1. Dynamically predicting start and end times for batches and operations and tagging batch events
2. Maintaining the dynamic schedule of all batches, including their current state
3. Dynamically detecting resource requirements and resource availability
4. Updating production scheduling with modifications to the schedule

Additionally, managing batch resources involves:

1. Receiving the detailed schedule
2. Dynamically detecting conflicts between resources needed and those that are available
3. Granting “permission” to unit to establish resource link
4. Arbitrating multiple requests for resources
5. Tracking and maintaining all batches, ready to run, in progress, completed, or aborted

Finally, batch management provides functions to acquire and manage batch information, such as:
1. Collecting and reporting batch information by batch, operation, phase, time, or event
2. Providing in-progress or complete batch reports
3. Archiving and retrieving batch data in batch history

A batch report can include recipe data, snapshot process data, or batch data in response to the recipe or on an ad hoc basis necessary for documenting the batch.
This includes operator modifications, historical trends, reports, and other information that may be available to the operator.

Unit Supervision

A unit consists of a physical grouping of equipment as well as the unit control functions required to carry out the execution of a batch.

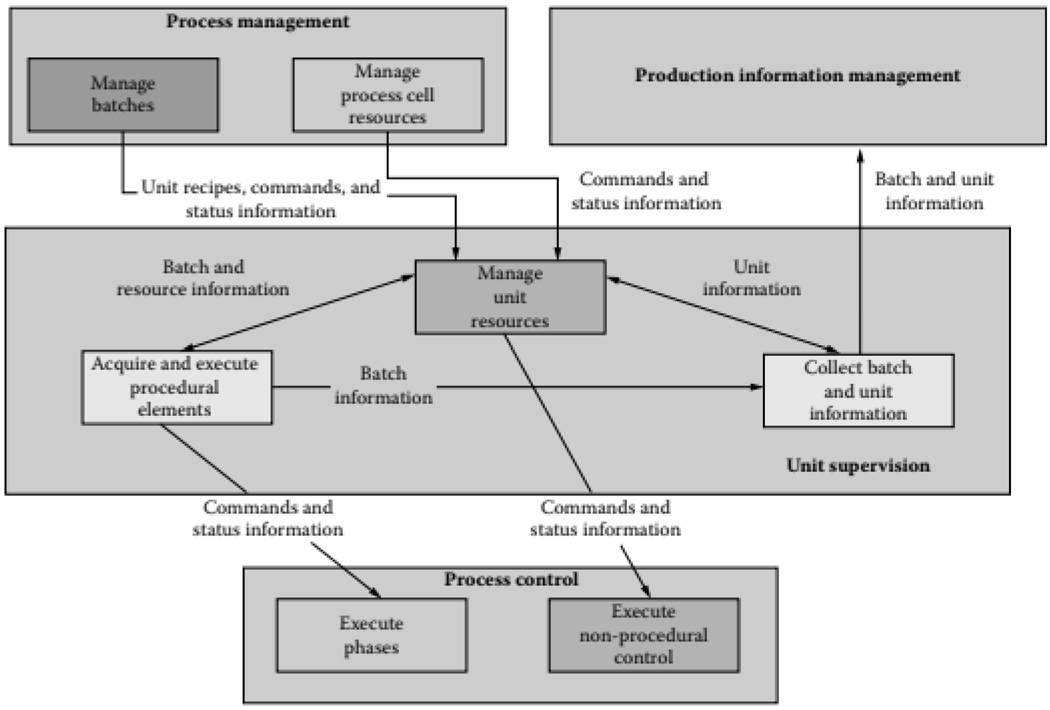
A process unit consists of a group of mechanical equipment; each piece performs, in a somewhat independent manner, a portion of the chemical process.

Examples of process units: Filters, batch reactors, heat exchangers, and distillation columns. Process control involves the actions required to perform the unit operations. Examples are charging, heating, cooling, agitating, reacting, discharging, and washing.

Unit supervision interfaces with the user, batch management, sequential control, regulatory control, and discrete control in performing its functions of

(1) communication with other units, equipment modules, and control modules;
(2) acquisition of resources;
(3) unit procedure execution; and
(4) exception handling.

Unit Supervision model:



Unit supervision requires certain information from batch management. The most important information is the recipe information required to run the unit. This recipe information contains the executable logic as well as formula information.

Unit supervision performs the unit procedures, operations, and phases in the order they are to be run; performs exception logic when some abnormal condition arises during execution; and downloads parameters from the formulas to the control modules.

When more than one processing unit affects the status or use of a resource, the resource is designated as a common resource. Common resources almost always exist with parallel and series/parallel batch process structures. A common resource may either be required exclusively or can be shared.

Unit supervision coordinates with other units to account for exclusive-use and shared-use resources.

Exclusive-use resources can be used by only one unit at a time. This means that some mechanism must be in place to prevent more than one batch from trying to use the resource at the same time. Also, the batch scheduling system must take this exclusive resource into consideration. Another problem is associated with distribution of risk in control systems.

If a controller module containing the exclusive-use resource fails with no backup, all units utilizing the resource are affected. Shared-use resources are associated with units that can simultaneously use the common resource. A unit should not be able to deactivate the resource while other units are using it, and the capacity of the resource should not be exceeded by multiple users.

The engineering of the equipment into units greatly affects how shared and exclusive resources are handled, which translates into the overall modularity of the batch control. As a batch processes through one unit to the next, the use of the equipment providing the transfers must be coordinated.

Process Control

Sequential, regulatory, and discrete control functions interface directly with elements and actuators to cause changes in the process.

Discrete control is concerned with maintaining the process states at a target value chosen from a set of known stable states.

Regulatory control serves to maintain the measurements of a process as close as possible to their respective set point values during all events, including set point changes and disturbances.

Sequential control sequences the process through a series of distinct states as a function of time.

These types of control functions are implemented using control modules and equipment modules. A control module device is an item of process equipment that is operated as a single entity and that may have multiple states or values.

Discrete states are initiated (using hardware and software) to control discrete devices such as solenoid valves, pumps, and agitators. A control module loop is a combination of elements and control functions that is so arranged that the signals pass between elements for the purpose of measurement or control of the process variable. A proportional, integral, derivative (PID) control algorithm is a common control loop function.

An example of equipment module control is the sequential control of dehydrator bed control valves in order to put one bed on-line while the other bed is being regenerated according to a time schedule. Most of today's process control systems utilize function blocks as the tools to describe and implement control modules.

Process interlocking and advanced control, in the forms of feedforward, predictive, or model-based control, are additional control functions that reside at this level and serve to achieve a higher level of automation to obtain additional benefits.

As opposed to continuous processing, additional control algorithms and control methodology are normally used in batch processing. Functions such as time-based PID (heat soak ramps), charging algorithms, sequencers, and timers are often required. Techniques such as enabling/disabling control functions based upon a phase state, enabling/disabling alarms on devices and loops, and employing anti-reset windup protection on PI or PID loops are commonly used. Batch processes tend to be device-oriented, while continuous processes are predominantly loop-oriented.

Safety Interlocking and Process interlocking:

Safety interlocks ensure the safety of operating personnel, protect the plant equipment, and protect the environment.

These types of interlocks are initiated by equipment malfunction and usually cause shutdown. Often, a separate system is used in implementing the safety interlocks. This system includes the necessary redundancy and fault tolerance, and is independent from the other control functions.

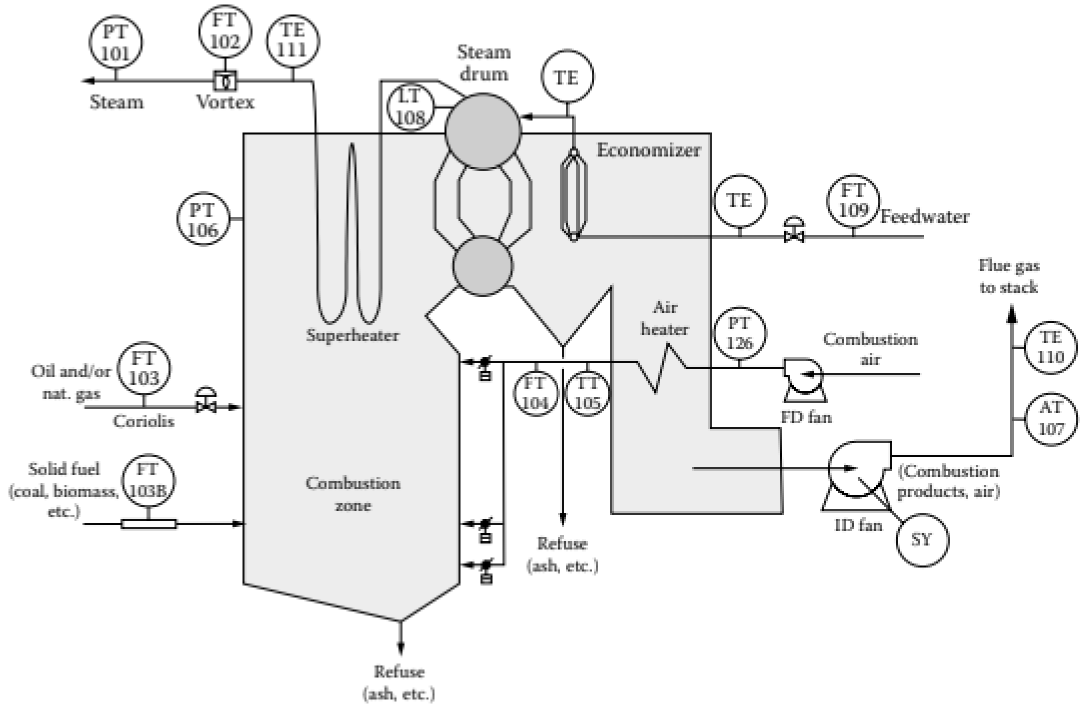
An example of a safety interlock is the stopping of a centrifugal compressor if its gear oil pump has failed, thus preventing mechanical damage.

Process inter-locking can be safety-related, but it is primarily associated with the process.

An example of a process interlock is to stop charging a material if the agitator is not running. A permissive interlock establishes an orderly progression of sequences. An example would be to not allow the feeding of an extruder before the barrel temperature has reached a minimum value.

Boiler control:

Role of sensors



The above diagram shows a typical boiler arrangement for gas, oil, or solid fuel. It also shows the in-line instruments used on a boiler, together with some advice on the type of sensor to be used.

The normal "on-line" requirements for steam boilers serve to control steam pressure within ±1% of the desired pressure; air/fuel ratio within ±2% of excess air (±0.4% of excess oxygen), based on a desired "load" vs. "excess air" curve; steam drum water level within ±1 in. of desired level; and steam temperature (where provision is made for its control) within ±10°F (5.6°C) of desired temperature. The efficiency of the boiler should be monitored within ±1%.

To performance the above process, it is necessary to install accurate sensors and to make sure that the load does not change more than 10–35% of full scale per minute, depending on the size, fuel type, boiler design, and that there are no boiler design problems limiting this ability. The various loops tend to interact, so that integration into an overall system is necessary both during design and when the loops are being "field-tuned."

Flow Detectors:

It provides the basis for both material and heat balance controls. Outlet steam flow measurement, particularly if it is used as part of the boiler firing rate control strategy, for environmental permit compliance, or for on-line efficiency or energy use calculations, should be pressure- and temperature- corrected to a true mass flow. Most steam flow sensors in use (orifice, flow nozzle, vortex-shedding meters, and so on) measure velocity, which translates directly to volumetric flow.

Multivariable transmitters with integrated pressure and temperature inputs and mass flow computation in the meter are preferred. If an uncompensated velocity or volumetric flow signal is all that is available, then it should be compensated to a true mass flow measurement in the control system using Equation 8.6(2):

$$F_C = F_A\left(\frac{P+P_0}{P_R}\right)\left(\frac{T_R}{T+T_0}\right)\left(\frac{X}{X_R}\right)\left(\frac{Q_R}{Q}\right) \qquad \textbf{8.6(2)}$$

where

F_C = compensated flow (mass flow)

F_A = uncompensated flow (velocity or volumetric measurement)

P = actual measured steam pressure

P_0 = conversion to absolute pressure (14.7 psi for imperial units and P in PSIG)

P_R = reference pressure (pressure at which primary flow element was specified and sized, converted to same units as $P + P_0$)

T = actual measured steam temperature

T_0 = conversion to Rankine or Kelvin scale (459.69 for °F to °R, 273.15 for °C to °K)

T_R = reference temperature (temperature at which primary flow element was specified and sized, converted to same units as $T + T_0$)

X = measured actual steam compressibility

X_R = reference steam compressibility (at conditions for which primary flow element was specified and sized)

Q = measured actual steam quality

Q_R = reference steam quality (at conditions for which primary flow element was specified and sized)

The compressibility and quality terms are often dropped, lacking a good measure of the actual values for these. In steam flow applications, the pressure compensation term is the most important one. From above equation, a differential pressure-type flow measurement, the process variable, FA, has already had square root extraction applied to convert it to velocity.

For successful control of the air/fuel ratio, combustion air flow measurement is important. In the past it was impossible to obtain ideal flow detection conditions. Therefore, the practice was to provide some device in the flow path of combustion air or combustion gases and to field-calibrate it by running combustion tests on the boiler.

These field tests, carried out at various boiler loads, used fuel flow measurement (direct or inferred from steam flow) and measurements of percentage of excess air by gas analysis; they also used the combustion equations to determine air flow. Because what is desired is a relative measurement with respect to fuel flow, the air flow measurement under these circumstances has historically been calibrated and presented on a relative basis.

Flow vs. differential pressure characteristics, compensations for normal variations in temperature, and variations in desired excess air as a function of load are all included in the calibration.

Using relative measurements, the desired result is to have the air flow signal match the steam of fuel flow signals when combustion conditions are as desired.

The following sources of pressure differential are normally considered:

• Burner differential (windbox pressure minus furnace pressure)

• Boiler differential (differential across baffle in combustion gas stream)

• Air heater differential (gas side differential)

• Air heater differential (air side differential)

• Venturi section or flow tube (installed in stack)

• Piezometer ring (at forced-draft fan inlet)

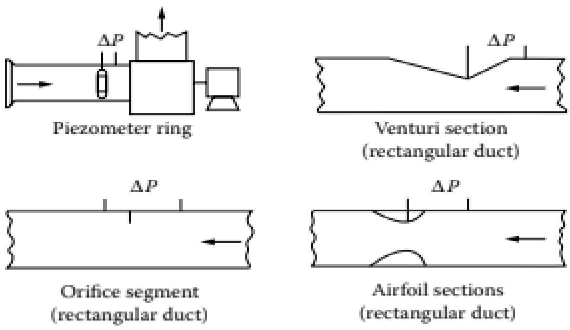
• Venturi section (section of forced-draft duct)

• Orifice segments (section of forced-draft duct)

• Airfoil segments (section of forced-draft duct)

Of these, the most desirable are the last four, because they use a primary element designed for the purpose of flow detection and measure flow on the clean-air side.

Traditional installations are shown in Figure 8.6c;



None of these sensors meet the dual requirement of high accuracy and range ability. In fact, they are of little value at 30% flow or less.

Flow Sensor Accuracy :

TABLE 8.6d
Flow Sensor Errors on Boilers

Flow Streams Measured	Type of Flowmeter	Inaccuracy (% of flow) At 10%	33%	100%	Rangeability	Limitation
Fuel (oil)	Coriolis mass flow	0.5	0.5	0.5	20:1	
Fuel (natural gas)	Coriolis	0.5	0.5	0.5	20:1	
	Thermal	5.75	2.27	1.25	100:1	
	Turbine	0.5	0.5	0.5	10:1 to 100:1	
	Ultrasonic	0.1–1.0	0.1–1.0	0.1–1.0	30:1 to 50:1	
Fuel (solid: coal, wood, etc.)	Gravimetric feeders or belt scales	0.25–0.5	0.25–0.5	0.25–0.5	3:1	
Fuel (pulverized coal)	Coriolis			0.5	3:1	Max. rate ~29 tons/hr
	Microwave			5.0	5:1	
Steam and water	Vortex shedding					
	Steam	1–1.5	1–1.5	1–1.5	10:1	Min. R_e = 20,000
	Water	0.5–1	0.5–1	0.5–1		Max. temp = 750°F (400°C)
	Orifice	NG*	2–5	0.5	3:1	Rangeability can be increased if using two conventional *d/p* cells or a "smart" *d/p* cell
Air	Area averaging pitot traverse station	NG	2–10	0.5–2	3:1	
	Multipoint thermal	5–20	2–5	1–2	10:1	Dual-range unit required
	Piezometer ring, orifice segment Venturi section airfoil section	NG	3–20	2–3	3:1	Cannot be used below 25% of max. flow

Some better flow sensors, such as the multipoint thermal flow probe or the area-averaging pitot stations provided with "hexcel"-type straightening vanes and with membrane-type pressure balancing d/p cells. Area-averaging pitot stations are also available in two-dimensional arrays, in a circular or rectangular mounting, that can average the entire flow-field.

Thermal (hot-wire anemometer) sensor arrays can also be fairly accurate, offer good turndown, and produce a signal in direct proportion to mass flow. These represent major advances in combustion air flow detection.

This table shows the measurement errors that can be anticipated. Unfortunately, as the flow is reduced, the error—in percentage of actual measurement—increases in all cases except the first two. With linear flowmeters, the error increases linearly with turndown of 10:1. In case of nonlinear flowmeters, the error increases exponentially with turndown. Therefore, at a turndown of 10:1, the orifice or pitot error increases 100-fold and causes these devices to become useless. This situation can be alleviated somewhat by the use of two d/p cells on the same element or by the use of "smart" units.

Based on the data in Table 8.6d, if the boiler efficiency is to be monitored on the basis of time-averaged fuel and steam flows, the lowest error that can be hoped for is around 1%. Similarly, the air/fuel ratio cannot be measured to a greater accuracy than the air flow. At high turndown ratios, this error can be very high. Considering that a 2% reduction in excess oxygen will increase the boiler efficiency by 1%, both the accurate measurement and the precise control of air flows are essential in boiler optimization. If combustion air temperature and pressure vary significantly, then air flow measurement can also be pressure- and temperature-compensated to a true mass flow, again, either with multivariable transmitters, or with Equation 8.6(2), dropping the compressibility and quality terms.

The impact of sensor inaccuracy on performance optimization elsewhere is not as critical. Standard instrumentation allows for the control of steam pressure within ±1%, furnace pressure within ±0.1 in. H_2O (25 Pa), water level within ±1 in. of desired level, and steam temperature to within ±10°F (5.6°C).

Safety Interlocking in boiler systems:

1.PURGE INTERLOCK Prevents fuel from being admitted to an unfired furnace until the furnace has been thoroughly air purged.

2. LOW AIR FLOW INTERLOCK OR FAN INTERLOCK Fuel is shutoff upon loss of air flow or combustion air fan or blower.

3. LOW FUEL SUPPLY INTERLOCK Fuel is shut off upon loss of fuel supply that would otherwise result in unstable flame conditions.

4. LOSS FLAME INTERLOCK All fuel is shut off upon loss of flame in the furnace, or fuel to an individual burner is shut off upon loss of flame to that burner.

5. FAN INTERLOCK Stops forced draft upon loss of induced-draft fan.

6. LOW WATER INTERLOCK (OPTIONAL) Shuts off fuel on low water level in boiler drum.

7. HIGH COMBUSTIBLES INTERLOCK (OPTIONAL) Shuts off fuel on highly combustible content in the flue gases.