

*Application Solutions Guide*

# CONVENTIONAL STEAM



*Experience In Motion*



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# THE GLOBAL CONVENTIONAL STEAM POWER PLANT LANDSCAPE

Thermal power generation involves the conversion of heat energy into electric power. Fossil fuel power plants as well as nuclear, biomass, geothermal and concentrated solar power (CSP) plants are all examples of thermal power generation. The modern era of thermal power generation began in the first decade of the 20<sup>th</sup> century with the introduction of the high-capacity horizontal condensing steam turbine. The steam used by the turbine was generated by burning a combustible fossil fuel such as coal, oil or gas in a high-pressure boiler. This became the “conventional” configuration of utility scale thermal power generation for most of the 20<sup>th</sup> century.

Since the early 1990s, combined cycle plants have taken their place alongside conventional steam plants as an important way of generating power from fossil fuels. In a combined cycle plant, a gas turbine drives an electric generator to produce electricity. To improve overall thermal efficiency and fuel utilization, the hot exhaust gases leaving the gas turbine pass through a heat recovery steam generator (HRSG) to produce steam that is used to generate additional power in a steam turbine. This steam turbine can be coupled to the opposite end of the gas turbine-driven generator or to a second stand-alone generator. As a result, the power generated by the gas turbine is augmented by about 50%, and the overall thermal efficiency of the plant is increased from about 37% to as high as 61%.

Combined cycle plants have become the preferred technology for gas-fired power generation for several reasons. The USC plant takes 40 to 50 months to build; a combined cycle plant can be built in 20 to 30 months. As a result, combined cycle plants can begin generating a return on investment two years earlier than a conventional steam plant of similar rating. Combined cycle plants can also handle starts and stops as well as rapid load variations more readily. Lastly, the 61% thermal efficiency of the most advanced combined cycle plants compares very favorably with the 47% efficiency of state-of-the-art, ultra-supercritical conventional steam plants.

The major limitation of combined cycle plants is that they cannot handle solid or dirty fuels. Integrated gasification combined cycle (IGCC) plants that convert coal, high-sulfur heavy oil or refinery residues to gas that can be used in a combined cycle plant are in their infancy and will not become a commercially viable alternative to subcritical, supercritical and ultra-supercritical conventional plants for another decade or so, if not later. As combined cycle has come to dominate the gas-fired power market, conventional steam plants continue to dominate the coal-fired market and, to a slightly lesser extent, the heavy fuel oil-fired market.

## THE GLOBAL CONVENTIONAL STEAM POWER PLANT LANDSCAPE – CONTINUED

The IEA estimates that 40% of all coal and CCGT capacity will be commissioned globally between 2016 and 2025. About 10% of gas-fired capacity and a proportion of oil-fired capacity will likely be for peak load generation and typically be provided by gas turbines in simple cycle. Oil-fired simple cycle plants are common in developing countries where electrical grids are poorly developed.

As a result, fossil capacity additions over the next 10 years should be split evenly between gas-fired combined cycle plants and coal-fired conventional steam plants. However, it is important to note the regional distribution of these additions. Most conventional coal-fired additions will occur in non-OECD countries and in non-OECD Asia. In contrast, two-thirds of combined cycle gas-fired additions will occur in the non-OECD. Almost half of combined cycle gas-fired additions will occur in North America, the EU, the Middle East and Latin America, which have been strong markets for Flowserve.

Conventional steam plants are also used for biomass- and waste-to-energy power generation. Though many of these plants are under 100 MW and operate at much lower pressures, the basic principles of operation and major components are the same. The power block of a concentrated solar power plant also uses conventional steam plant technology, but the boiler is replaced with a series of heat exchangers that transfer solar heat from a heat transfer fluid or molten salt to the feedwater in the power block. Biomass, waste to energy and concentrated solar power represent a small portion of forecasted global thermal capacity through 2025.

## A Closer Look at Conventional Steam Power Technology

### Basics

All conventional steam power plants utilize some form of the Rankine thermodynamic cycle. It involves the conversion of the chemical energy of fuel into thermal energy in the form of steam. The thermal energy in the steam is converted to mechanical energy in the turbine and then to electrical energy in the generator.

At its most basic level, a pump is used to pressurize water, which is fed to a boiler where it is evaporated into steam at constant pressure by the addition of heat. Steam pressures may vary from as low as 30 bar (435 psig) in a small waste-to-energy boiler to as high as 270 bar (3900 psig) in a large, ultra-supercritical, coal-fired plant. This high-pressure steam is then expanded through a steam turbine producing work, which is used to drive an electric generator. The saturated steam leaving the exhaust of the turbine then enters a condenser where it is cooled by an external supply of cooling water, causing it to condense. The condensation process creates a vacuum in the condenser, the level of which is mainly dependent on the temperature of the external cooling water. Typical condenser pressures range from 0.068 to 0.085 bar (0.98 to 1.23 psia). The condensed liquid is returned to the suction of the pump to complete the cycle.

Commercial power plants incorporate several thermodynamic improvements to the basic Rankine cycle. These are illustrated in Figure 2 and described below.

Increasing turbine inlet steam pressure (and temperature) in the basic Rankine cycle increases the thermal efficiency of the cycle; however, it also causes condensation to occur at the exhaust end of the steam turbine (a more detailed explanation of why this is so can be found in the Appendix). This condensation can cause damage to the blades of the steam turbine. Condensation can be reduced by reheating the steam after it has passed through the high-pressure section of the steam turbine. Reheat allows the boiler to be designed for higher operating pressures and also increases the average temperature of the steam in the turbine, leading to improvement in the efficiency of the cycle.

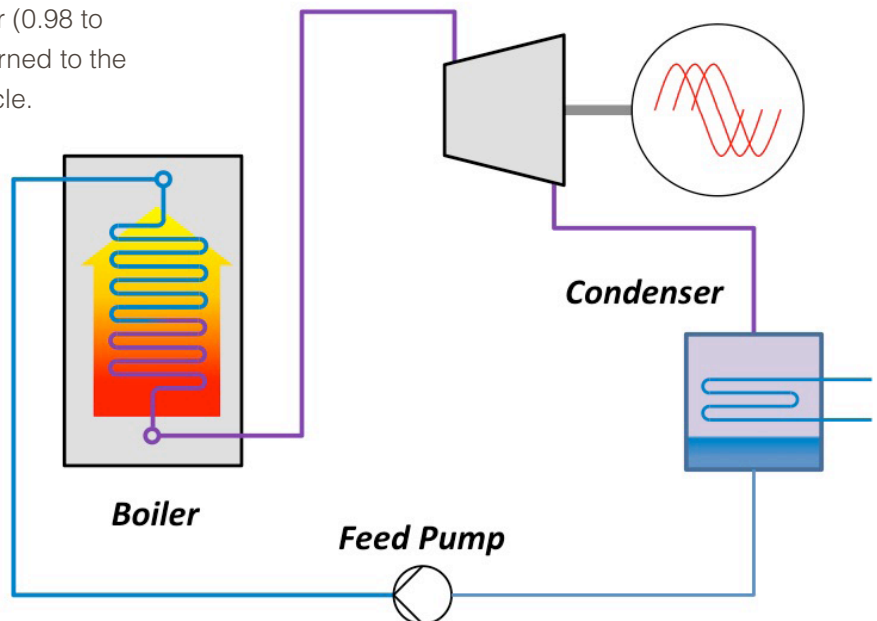


Figure 1: Basic Rankine water/steam cycle

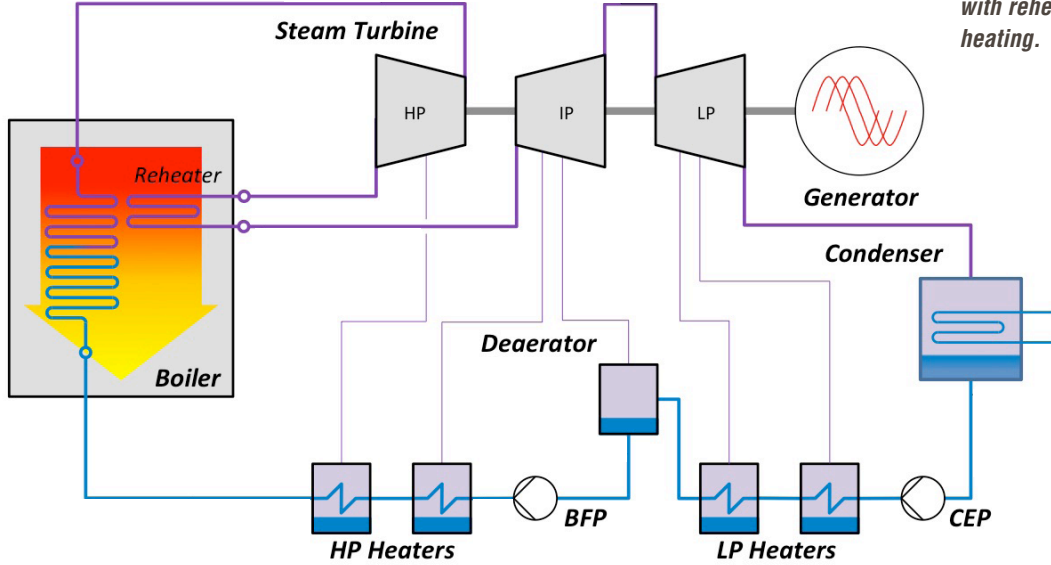


Figure 2: Simplified ultra-supercritical power plant with reheat and feedwater heating.

Another thermodynamic improvement to the performance of the Rankine cycle is extraction and regeneration, which is more frequently referred to as *feedwater heating*. Steam is extracted from various points in the steam turbine's high, intermediate and low-pressure sections and delivered to a series of feedwater heaters that pre-heat the condensate in stages before it enters the boiler. Figure 2 shows two low-pressure *closed feedwater heaters* between the discharge of the condensate extraction pump (CEP) and the suction of the boiler feedwater pump (BFP) and two high-pressure closed feedwater heaters between the BFP and the boiler. In a closed feedwater heater, the heating steam and the feedwater do not mix. The condensed heating steam is collected in the bottom of each closed heater, cascaded back to the heater directly upstream of it, and then flows back to either the deaerator (in the case of the HP heaters) or the condenser (in the case of the LP heaters).

The *deaerator* indicated in Figure 2 is a special type of *open feedwater heater* designed to not only heat the feedwater but also remove non-condensable gases from the feedwater stream. In an open feedwater heater, the steam and feedwater

are in direct contact; the deaerator is designed in such a way to ensure that the incoming feedwater is atomized in the presence of the steam to allow the most effective removal of the non-condensable gases. It should be noted that the steam provided to the deaerator is often called *pegging steam* and the valve controlling the steam flow is a *pegging steam valve*.

Figure 2 has been simplified for clarity. Large power plants typically have at least four (4) low-pressure (LP) feedwater heaters and three (3) high-pressure (HP) feedwater heaters. Many plant designs split the HP feedwater section into two parallel 50% trains. It should also be noted that large power plants typically use two or three LP turbines operating in parallel and coupled on the same shaft line. Since it is very common for the first two stages of LP feedwater heaters to be installed in the shells of the condenser directly under the LP turbines, this also increases the total number of heaters needed. This in turn greatly increases the number of valves associated with the feedwater heating system than would otherwise be apparent from referencing Figure 2; these valve applications are of particular interest to Flowserve.

## Plant Configurations and Sizes

### Subcritical, Supercritical, Ultra-Supercritical

The key differentiator in conventional utility scale power plants today is whether they operate at subcritical or supercritical conditions. Below the critical point, water can exist as both a liquid and a vapor (steam) under the same pressure and temperature conditions. This is apparent when water is heated at sea level in an open container where the water can be seen to exist in both its liquid and vapor phases while it is boiling. At supercritical conditions, water changes to steam continuously in one homogeneous phase (see Appendix for further details).

Typical turbine inlet steam conditions for utility scale conventional power plants are given below along with resulting thermal efficiencies:

- Subcritical: up to 175 bar and 565°C (2534 psia/1050°F): 37% thermal efficiency
- Supercritical: up to 250 bar and 565°C (3690 psia/1050°F): 42% thermal efficiency
- Ultra-supercritical: up to 290 bar and 620°C (4200 psia/1148°F): 45% thermal efficiency

The higher pressures and temperatures used in supercritical and ultra-supercritical power plants place higher demands on pumps and valves.

## Power Plant Ratings

Conventional thermal power plants vary substantially in size. At the end of 2015 in China, about a quarter were between 100 and 300 MW, while nearly half were between 300 and 600 MW. All were subcritical. The balance represented supercritical and ultra-supercritical units rated at either 660 or 1000 MW. In recent years, the Chinese government has discouraged new construction of the less efficient and smaller subcritical units and is now calling for the rapid retirement of all subcritical capacity. Supercritical 660 and 1000 MW units accounted for more than half of coal-fired capacity commissioned in China in 2015.

In India at the end of 2014, a low number of supercritical or ultra-supercritical units totaling 63 GW were under construction, while a significant number of subcritical units with an average size of 356 MW were also under construction. India's goal is to ensure that at least 80% of all new capacity additions in the coming years use supercritical and ultra-supercritical technology. Supercritical and ultra-supercritical units in India are either 660 or 800 MW, but the country has plans to introduce 1000 MW units in the near future.

The other major markets for coal-fired power plants are Southeast Asia and Africa. A significant part of this market will still opt for subcritical technology due to lower cost, cheap domestic coal supplies, and because existing grids are not well-suited to larger units.

## Flue Gas Desulfurization (FGD)

Flue gas desulfurization involves the post-combustion removal of sulfur dioxide from coal and heavy oil or residue-fired power plant flue gas streams. While  $\text{SO}_2$  is not a greenhouse gas, it reacts with water, oxygen and sunlight to produce sulfuric and nitric acids, resulting in acid rain. There are several wet and dry processes available to remove  $\text{SO}_2$  from flue gas.

The FGD technologies of most interest to Flowserve are wet limestone and seawater scrubbing. The overnight capital cost of wet limestone FGD is estimated to be higher than seawater FGD.

## Wet Limestone FGD System

In this process, sulphur dioxide in the flue gas is removed by direct contact with a limestone ( $\text{CaCO}_3$ ) slurry in an absorber vessel. Aeration is provided in the vessel to convert the calcium sulfate ( $\text{CaSO}_4$ ) and calcium sulfite ( $\text{CaSO}_3$ ) produced from the reaction to gypsum ( $\text{CaSO}_4 \cdot \text{H}_2\text{O}$ ), which is a saleable product. The flue gas is conveyed from the boiler through the electrostatic precipitator (ESP) by an induced draft (ID) fan (see Figure 2 “From ID Fans” in the top right). The gas is cooled before it enters the absorber by the stream of clean cool flue gas leaving the absorber. The limestone slurry is sprayed into the absorber at three or four different levels near the top of the vessel by the absorber recirculation pumps. These large single-stage end suction slurry pumps are key components in the FGD unit.

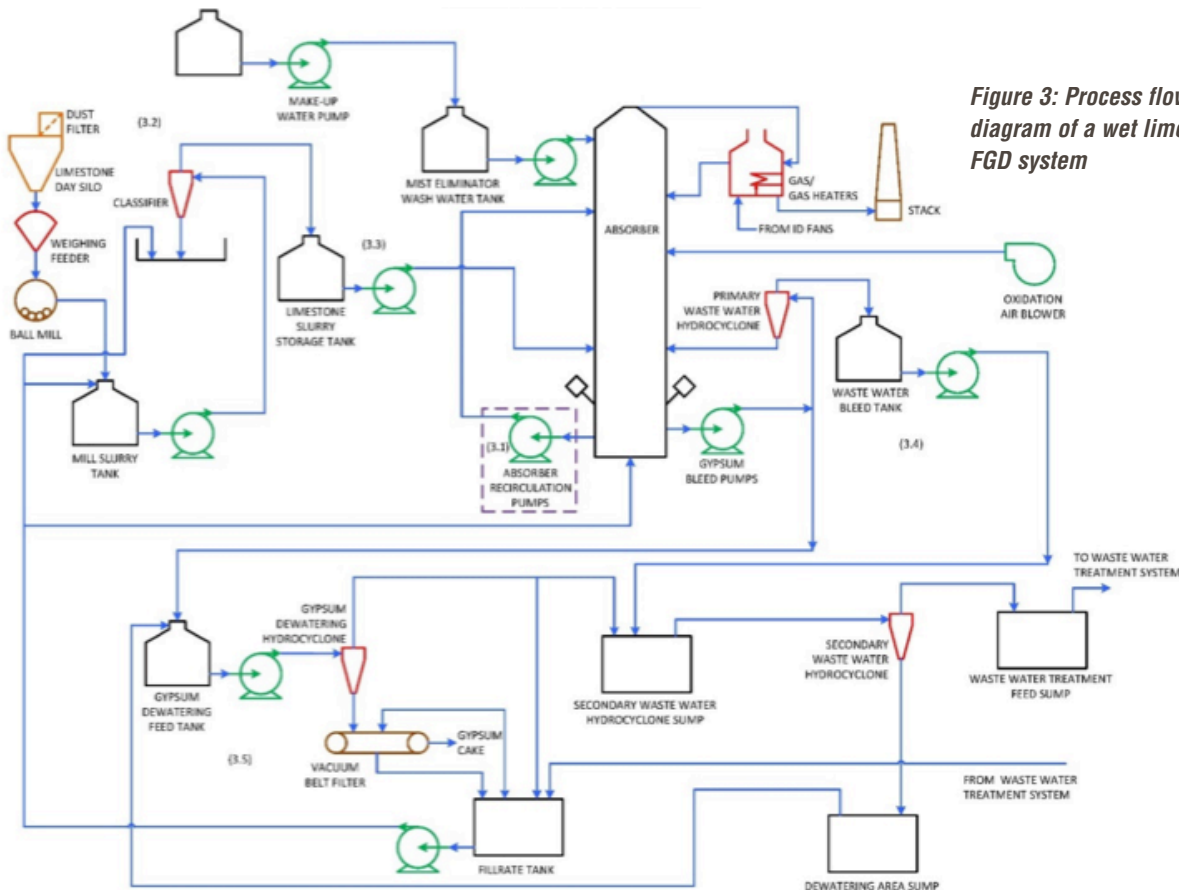


Figure 3: Process flow diagram of a wet limestone FGD system



The size of the pumps is directly related to the sulfur content of the fuel, but a typical 500 MW subcritical low sulfur coal-fired power plant in India equipped with limestone FGD requires three absorber recirculation pumps. Each pump delivers slurry to a different level in the absorber. The slurry is 10–20% solids by weight, and 90% of the solids are less than 180 µm (0.007 in). Pumps are generally rubber-lined with high-chrome impellers, but silicon carbide ceramics are also used. Flowserve does not have a competitive offering for this service.

Other sub-systems in a wet limestone FGD unit include the slurry or absorbent preparation, storage and delivery systems, the gypsum bleed system and dewatering systems, as well as the wastewater treatment system. All of these use a variety of small- to medium-size slurry and clear water pumps; some or all of these may be purchased as part of a package with the absorber pumps.

A typical wet limestone FGD system requires anywhere from 100 to 200 valves. Knife gate valves are used on many of the slurry services in diameters up to 60 inches. For smaller-diameter applications, diaphragm valves with thick rubber liners and pinch valves are most common, but ceramic ball valves and rubber-lined butterfly valves are also used. Once again, Flowserve has a limited portfolio for these applications.

Mechanical seals present the main opportunity for Flowserve in the wet limestone FGD market. Flowserve has a successful track record with end user and absorber pump OEMs for virtually every sealing application.

## Seawater FGD System

Seawater FGD is a convenient and economical way to remove sulfur dioxide emissions for coastal power plant installations and is ultimately a larger opportunity for Flowserve. This simple process requires no bulk chemicals, has low capital and operating costs, and produces no by-product requiring disposal.

Figure 4 provides a simplified view of the process. The system is located in the flue gas path after the selective catalytic reduction (SCR) unit and the electrostatic precipitator (ESP). The former reduces nitrogen oxides and the latter removes fine particles. Flow is maintained with an induced draft fan after the ESP unit. The flue gas flows upward in the absorber against the downward-flowing seawater absorbent. The packing in the absorber maximizes the contact between the flue gas and the seawater. The seawater absorbent is provided by vertical

wet-pit pumps, which (depending on the flow requirements) may be installed in the condenser cooling water outlet channel as indicated. The clean gases then return to the heat exchanger where they are warmed before being discharged to the stack. The reject acidified seawater passes on to a mixing basin for dilution and then to an aeration basin, where sulfites are converted to sulfates, carbon dioxide is removed, and oxygen is added before returning to the sea.

Seawater flow requirements for the seawater flue gas desulfurization (SWFGD) absorber pumps vary widely per the sulfur content in the fuel, which may range from as low as 0.5% for coal to as high as 3.5% for some heavy fuel oils (HFO).

Large-diameter butterfly valves similar to those used in the condenser cooling water system would also be used in the SWFGD unit.

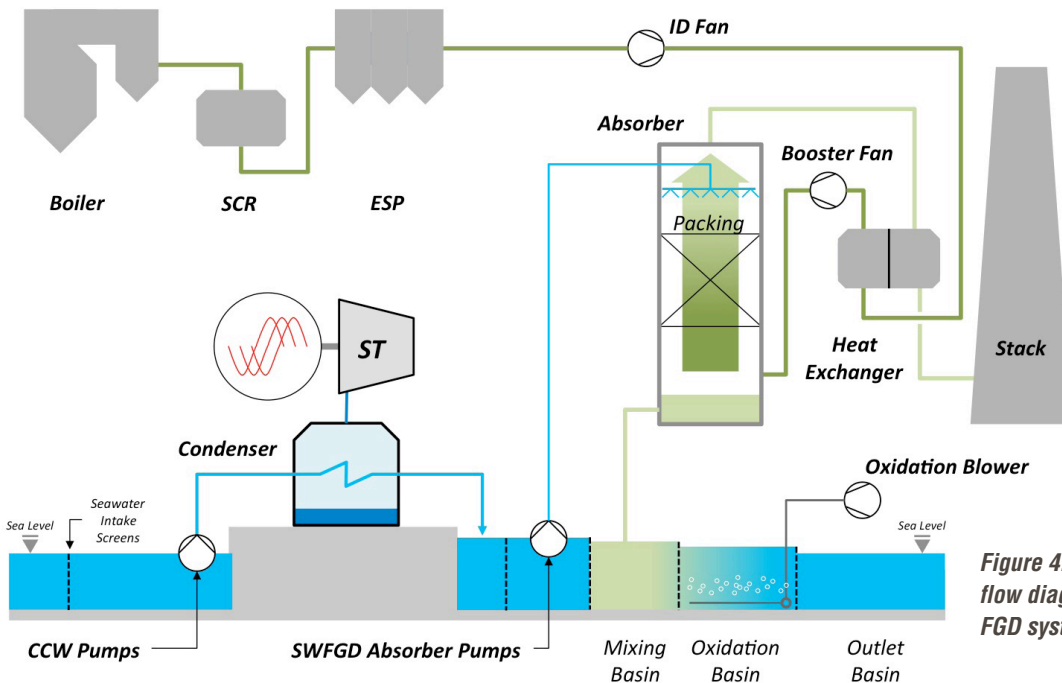


Figure 4: Simplified process flow diagram of a seawater FGD system

## Conventional Steam Project Models

Conventional power plants are conceived and constructed under varying financial, regulatory and market circumstances. Understanding these can be vital to developing a successful sales strategy.

The ownership and operation of power plants take many different forms. First is the publicly owned utility that operates in a rate-based regulated market and is vertically integrated, owning not only the generation assets but also the transmission and retail distribution network. Many developing countries have national utilities of this type. In developed countries this type of utility, if it exists at all, generally occurs at a state or municipal level. Regulated rate-based utilities can also be privately owned; this is a very common arrangement in many parts of the U.S. National, regional or state-based regulated utilities, whether publicly or privately owned, often have large experienced engineering, operations and maintenance organizations. These types of organizations are much more likely to take an active part in the specification and evaluation of equipment proposed by the EPC contractors. Equipment specifications may have been developed over many years, and it can be very difficult to have any proposed deviations accepted. While EPCs generally work under lump sum, fixed price contracts, utilities can exercise important control on equipment purchased by them by including approved vendor lists in bid specifications.

The situation with power plant owners in deregulated markets is somewhat different. One common project model is the Power Purchase Agreement (PPA) between an independent power plant (IPP) developer and an offtaker or purchaser of the power. PPAs guarantee the quantity and price of the power to be purchased for an extended time period and thus facilitate project financing. The offtaker is typically a public utility. These projects tend to be very sensitive to the costs of the project because the PPA is often awarded on a competitive

auction basis. IPPs are often owned by groups of investors who do not have an extensive portfolio of generating assets or a great deal of engineering and operating expertise. Thus, they may tend to take a more “hands off” approach to equipment selection on the project. However, PPAs often have penalties tied to plant availability and project completion dates, so developers are not indifferent to reliability and quality.

PPAs have been used extensively in India. In the first decade of this century, many private Indian developers subcontracted plant construction to Chinese construction firms due to an urgent need to build plants at the lowest possible cost to bid PPAs competitively.

Power plant developers and owners typically hire a consulting engineering company or companies (also called *owner's engineer*) that will be involved in project planning, basic design, siting and permitting activities as well as the development of detailed project specifications for EPC bidding if they do not have that capability in-house. The owner's engineer will not actually procure anything but may have substantial impact on the content of specifications, so it is important for Flowserve to be engaged with them by providing strong technical support on pumps and valves. In some cases, the owner's engineer may also be involved in the bid evaluation and purchase decision and provide technical advice to solve problems during manufacturing, startup and commissioning.

Most power plant projects are realized under lump sum turnkey (LSTK) engineer, procure and construct contracts awarded to large EPC contractors by the project owners. The EPC contractor may be a pure EPC company or joint venture, or the original equipment manufacturer (OEM) supplying the major equipment for the project (gas turbines, steam turbines and generators). In some cases, there may be more than one EPC contract, with each handling a specific part of the scope.

EPCs conduct business in a highly competitive market; their contracts can involve substantial risk. EPC contracts are fixed price, with a high potential for cost overruns. They typically include guarantees on plant performance and project milestones that are subject to liquidated damages.

As a result, sub-vendors who provide competitively priced products and strong sales support at the contractor bidding phase as well as strong project and supply chain management during order execution, erection, commissioning and warranty are well positioned to succeed in this market. The ability to source multiple packages from a single supplier can also reduce project management costs and is therefore seen positively by many EPCs.

In China, design institutes (DIs) fulfill most of the key functions of an EPC. Many of these are ultimately state-owned and tend to be bureaucratic and cautious. Elaborate bid evaluation processes are often devised and used to ensure transparency in the selection of equipment and the awarding of contracts. Technical compliance (a minimum of technical exceptions), terms of payment, terms & conditions, and references (in China) may receive ratings equal to or greater than price. Once a contract is signed, it can be very difficult to get design changes approved, even if they offer the customer an evident benefit.

When major original equipment manufacturers act as the EPC, they share many of the same concerns as pure EPCs as noted herein, but other factors may enter into their decision-making process. One important example is that their reputation for supplying high-quality reliable turbines and boilers cannot be compromised by the failure of a pump or valve. They also may be more inclined to try to develop long-term agreements with fewer key equipment suppliers to enhance their overall equipment portfolio as they go to market. This would be particularly true the more standardized the component.

# THE CONVENTIONAL STEAM POWER-FLOWSERVE INTERFACE

## Business Impact and Focus Areas

### The Big Picture

The IEA is forecasting that coal-fired gross capacity additions between 2016 and 2025 will be well behind renewables and slightly behind gas. The regional distribution of these capacity additions is also worth noting. Almost 92% of all coal-fired capacity additions will occur in non-OECD countries; 77% will occur in non-OECD Asia, China and India. According to the IEA, this situation will be almost exactly reversed between 2026 and 2040, with India leading GW over China.

Some of the gas-fired capacity additions in the coming years (perhaps 10%) will be in the form of simple cycle gas turbine peaking installations, which require few pumps and valves; some will also come from the conversion of existing coal-fired plants to natural gas (perhaps another 10%). But the major portion will come from combined cycle generation. This combined cycle capacity will come from new installations as well as the conversion of existing simple cycle installations.

Based on the GW figures provided by the IEA, total annual capex investment for conventional fossil steam plants could be more than \$1.5B for pumps and valves over the next 10 years.

### The Flowserve Fit in Conventional Steam Power

Flowserve has been a leader in the [power generation industry](#) for close to 100 years. Its reputation as a provider of engineered equipment is largely based on its participation in the power and oil & gas markets. Flowserve is a leading player in all sub-segments of the thermal power market, including conventional fossil-fired steam, nuclear, combined cycle, biomass concentrated solar power and geothermal.

# PRODUCTS FOR STEAM POWER — AT A GLANCE

Conventional power plants offer difficult challenges for pumps, valves and seals. High operating temperatures and pressures are characteristic of many applications, and the push toward ever higher pressures and temperatures to achieve higher thermal efficiency requires constant innovations in pump, valve and seal technologies. The age of the fully base-loaded power plant is over. Advancements in boiler and turbine designs now permit quicker plant startup and more rapid load variation. As a result, [pumps](#), [valves](#) and [seals](#) must be designed and selected to handle severe transient operating conditions. Flowserve has a [portfolio of products](#) up to this task.

## Pumps

A typical steam power plant may have no more than 50–100 pumps. A few key services (main feedwater, condensate extraction and condenser cooling) account for a very high percentage of the total pump value. Below are the major pump categories and Flowserve designations:

- Multistage between bearings, double casing pumps (CHTA, CSB)
- Vertical wet-pit, single-stage pumps (VCT, VTP)
- Concrete volute pumps (BSV and BCV)
- Vertical canned multistage pumps (APKD)
- Horizontal single-stage, axially split pumps (LNN, LR)
- High-capacity, end suction overhung pumps (FRBH, Mark 3™ Grade 4)
- General service end suction pumps (Mark 3, ZLN, CBT)
- High-pressure, high-temperature, end suction pumps (HPX)
- Sump pumps (CPXV, ESP3)
- Liquid ring vacuum pumps (LEH, LPH)

## Valves

There can be up to 5000 valves in a conventional steam plant. A large share of these are small bore general service valves, which are not discussed in this guide. Flowserve targets the severe service and control valve applications in conventional steam plants, even though the quantity of valves may be fairly small. Some examples include the following valves and related equipment:

- Edward® gate, globe and check valves
- Valtek® globe control valves
- Valtek Valdisk™ double offset butterfly valves
- Limitorque® MX multi-turn, non-intrusive actuators

## Seals

Flowserve pumps are sold in the conventional power industry with Flowserve mechanical seals, unless the purchaser specifies otherwise. Virtually all applications can be handled with the following products:

- DHTW for the most severe high-energy boiler feed pump applications
- QB for main feedwater, startup feedwater and condensate extraction applications
- PSSL split seal for condenser cooling, though packing is still the most popular solution
- ISC2-P pusher seals can be used for most other applications.
- RIS, SLM and SLC slurry seals for limestone flue gas desulfurization and ash handling

## Estimated Values by Plant Size

The value of pumps and valves can also be fairly closely correlated with the plant rating.

The estimate is based on a blended market level price for Chinese and Indian ultra-supercritical projects. As a result, pumps represent approximately 1.0% to 1.5% of the total plant capital cost. Neither the plant nor pump capital cost figures include the cost of FGD systems.

Virtually all of the pump capex spend is procured through the EPC contractor. Recirculation pumps, which Flowserve does not offer, would be procured by the boiler OEM and the condenser vacuum pumps through the condenser OEM.

Approximately 65% to 75% of the pump spend is associated with the main feed, condensate extraction and condenser cooling water pumps.

The value of the valves is more difficult to precisely determine, but a figure 20–25% higher than the pumps would be consistent with other plant types. Seawater cooling would have less impact on total valve cost than it does on pump cost. Thus, valves represent about 1.25% to 1.50% of total capital cost. It is estimated that only 60–65% of the valve spend is through the EPC. The rest comes through the boiler and steam turbine OEMs.

Critical service valve applications are estimated to account for about 60–70% of the valve spend.

# FLOWSERVE PRODUCTS IN CONVENTIONAL STEAM POWER

*In this section, you will find a detailed listing and description of the key products and capabilities Flowserve offers for conventional steam power plants.*

## Conventional Steam Applications Overview

The process flow diagram on the following two pages provides a simplified schematic of the main components in an ultra-supercritical, coal-fired power plant. The main pump and valve applications are identified in the discussion that follows after the diagram. Typical values of flow, temperature and pressure are given where deemed appropriate. These values are from a heat balance diagram for a typical 600 MW, ultra-supercritical power plant with steam turbine, which is referred to as the “reference plant”.

Figure 2 provided a very simple overview of the process flow of a power plant Rankine cycle, with reheat and feedwater heating that should help as a guide in understanding Figure 5. The best way to study the diagram is to start at the condensate extraction pump (A) and follow through the low-pressure feedwater heating system to the deaerator and then on to the feed pumps (C) to the high-pressure heaters and boiler. Steam emerging from the boiler then goes through the LP turbine, reheater, IP turbine and LP turbine returning to the boiler. Water is shown in blue; steam is purple.

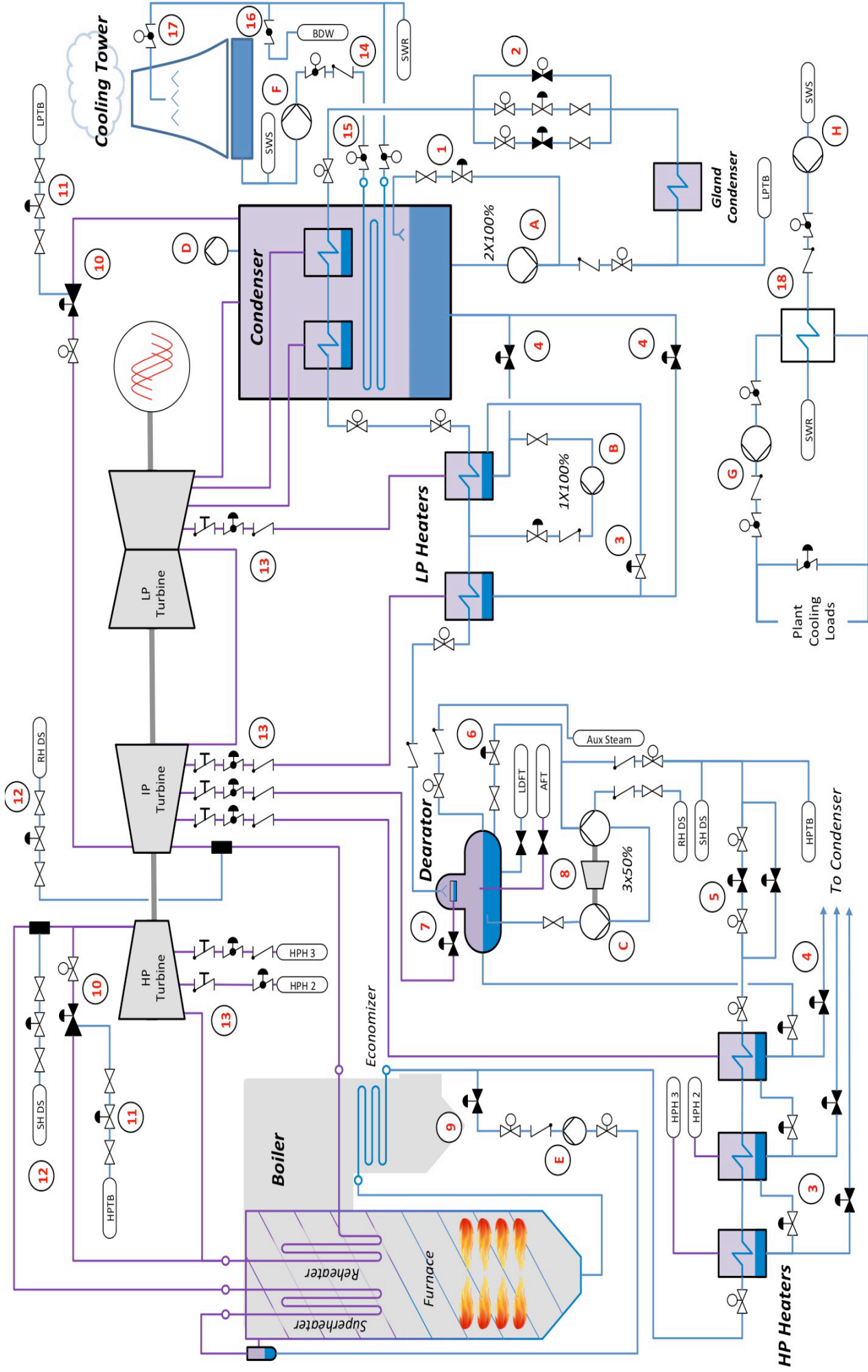
Figure 5 does not include the following systems: raw water treatment; ash handling; and demineralized water production. These systems include a variety of general services pumps and valves, but are not described in detail in this guide.

There is a significant additional valve opportunity with the boiler and steam turbine OEMs, which cannot be adequately covered in this guide or depicted in a simplified process flow diagram.



**THE CONVENTIONAL STEAM POWER-FLOWERVE INTERFACE**

**Main pumps are letters and main valves are numbers.**



## Pumps for Conventional Steam Plants

### Condensate Extraction Pumps (a)

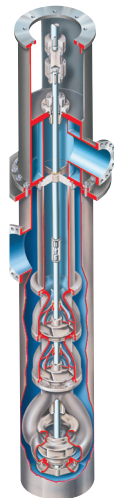
Condensate extraction pumps are used to pump condensate in the hot well of the condenser through the steam turbine gland condenser and onward to the low-pressure heater drains. The condenser operates at a vacuum of approximately 0.045 bar absolute (0.65 psia). The condensate is at saturation conditions with a typical temperature of 38°C (101°F). This means that the net positive suction head available (NPSHA) at the liquid level in the condenser is zero. As a result, a canned vertical multistage pump is typically used for this application. The setting (distance from mounting plate to the bottom end of the pump) is selected to provide sufficient NPSHA to the first-stage impeller. The pump is equipped with a double-suction, first-stage impeller to provide low NPSHR and thus minimize the length of the suction can.

The condensate extraction pumps also supply the spray water for various desuperheating applications, including steam turbine gland steam, low-pressure turbine bypass, drain flash boxes and others.

Condensate extraction pump sealing systems must prevent air from entering the pump when on standby under a vacuum. This is accomplished with API Plans 13 and 32 flush piping systems.

The most common pump configurations are 2x100% or 3x50%.

### APKD



**Condensate Extraction  
Heater Drain**

### Heater Drain Pumps (B)

While it is possible to cascade the condensate drains of the LP heaters back to the condenser, plant performance can be improved by pumping the drains directly into the feedwater line. The process flow diagram shows a heater drain pump (also called a *drain recovery pump*) pumping the drain from the third and fourth LP heaters back into the feedwater line between them. Various strategies are available that may involve pumps at more than one stage in the feedwater heating process.

APKD pumps or the single-suction, first-stage APKC are typically used for this application because of the low NPSH available. The flows are substantially lower than for the condensate extraction pumps. In our reference plant, a 100% heater drain pump located at the third LP heater drain would handle a flow of about 340 m<sup>3</sup>/h (1500 US gpm). Unlike the condensate extraction pumps, which operate at relatively low temperatures, heater drain pumps can see temperatures as high as 148°C (300°F), depending on where they are located.

### Main Feedwater Pumps (c)

The purpose of the main feed pump is to deliver feedwater from the deaerator through the high-pressure heaters to the boiler economizer. The main feed pumps also supply spray water to the superheater and reheater attemperators.

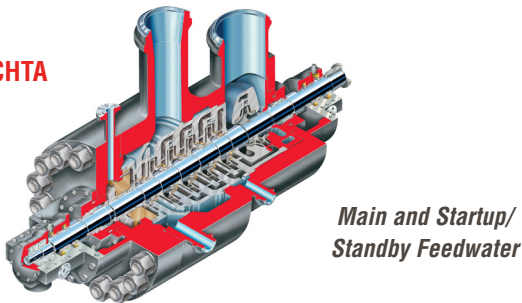
Multistage in-line diffuser double-case barrel pumps are typically specified for main feedwater service in large utility power stations. The Flowserve product of choice for these applications is the CHTA. The pressure requirements in supercritical and ultra-supercritical plants require that the feed pumps run at a high speed. As a result, a booster pump running at a lower speed (usually four-pole speed) is required to provide the main pump with sufficient NPSH. The HDX is the preferred choice for booster pump service in large plants, but HPX pumps can sometimes be used in smaller plants.

The standard pump configuration used in India is two 50% main pumps with each directly driven by a customer-supplied steam turbine. The booster pump is driven off the back end of the steam turbine through a reducing gearbox. A motor-driven 50% (alternately 35%) pump is also provided for startup and standby operations. A four-pole motor drives the main pump through a combined variable speed fluid coupling and speed increaser. The booster pump is driven directly off the back end of the four-pole motor.

Plants in China typically use two 50% pumps or one 100% main pump driven by steam turbines. The booster pumps are driven through a reducing gearbox, either off the back end of the turbine or the outboard end of the main pump. The latter arrangement requires a long spacer between the two pumps to facilitate the removal of the main feed pump cartridge. One motor-driven startup pump sized for 5% of capacity may be provided. Some plants do not have any startup pumps and use steam from an auxiliary steam boiler to start the plant.

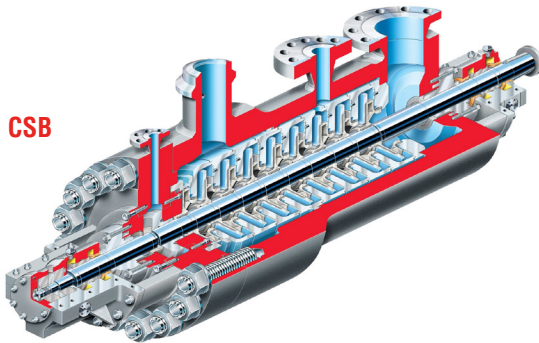
Smaller subcritical power plants sometimes use feed pumps directly driven by two-pole motors. These pumps often include a double-suction first stage, eliminating the need for a booster pump.

**CHTA**

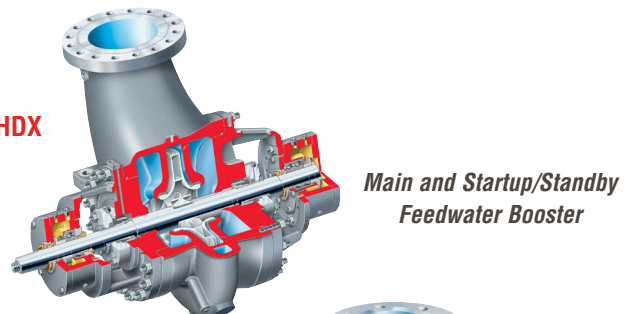


*Main and Startup/  
Standby Feedwater*

**CSB**

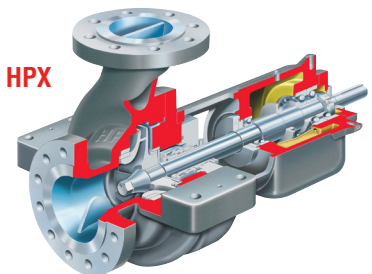


**HDX**



*Main and Startup/Standby  
Feedwater Booster*

**HPX**



### Condenser Air Evacuation Pumps (d)

The condenser is an airtight vessel where the steam exhausted from the turbine is cooled and condensed; a vacuum is formed in the condenser as a result of this condensation. The vacuum is determined by the temperature of the condenser cooling water (or the air temperature in case of an air-cooled condenser). The lower the temperature of the cooling medium, the lower the vacuum in the condenser. Typical condenser vacuums of 0.06 to 0.08 bar absolute (2.0 to 2.5 in Hg) are achieved in water-cooled condensers.

To maintain this low-pressure condition, it is essential that any air or other incondensable gases passing into the condenser with the steam be continuously removed. This is done with a single- or two-stage liquid ring vacuum pump. An ejector may also be used in series with the vacuum pump. Flowserve can provide complete systems for the application, including the ejector (as applicable), the liquid ring vacuum pump, a separator to separate the liquid from the gas, and a heat exchanger to cool the liquid returning to the vacuum pump.

Vacuum pumps are also used to create the initial vacuum in the condenser during startup. This operation is referred to as *hogging* as opposed to *holding* during normal operation. An important consideration in the selection of the pumps is the specified time to bring the condenser to full vacuum at startup. One arrangement is to have 2x100% pumps that are both operated during hogging. Another would be 3x50% pumps where only one operates during holding. It is also possible to have two differently sized pumps: one for holding and one for hogging.

Other vacuum pump applications not specifically illustrated on the process flow diagram include condenser water box priming. Condensers may be primed using the circulating water pumps, but some designers prefer to use a separate vacuum system to accomplish this task. Lastly, small SIHI® vacuum pumps can also be used in the deaeration of makeup boiler feedwater.

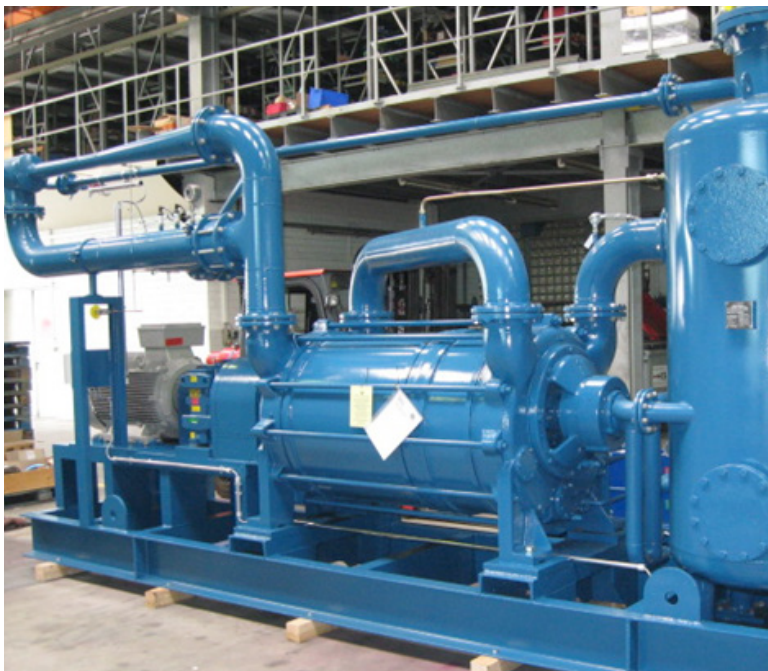


Figure 6: Vacuum pumps for STOE, Netherlands CCGT

#### LEH (single-stage)



#### LPH (two-stage)



Condenser Air Evacuation

### Boiler Recirculation Pumps (E)

Conventional subcritical boilers utilizing a steam drum must maintain circulation through the drum and boiler tubes; this is accomplished by either natural or forced circulation. Natural circulation boilers rely on feedwater temperature and the resulting density differences in the drum and vertical boiler tubes to promote circulation by gravity. Forced circulation boilers rely on a pump. Supercritical boilers do not require circulation when at normal operating conditions because they operate on the “once through” principle (see Appendix); however, they do require circulation at startup and low load conditions. A forced circulation system with a single-stage glandless wet motor pump is the standard solution adopted by supercritical boiler manufacturers today.

Flowserve does not have a current product offering for this application. The main vendors for boiler recirculation pumps are KSB, Hayward-Tyler and Torishima.

### Condenser Cooling Water Pumps (F)

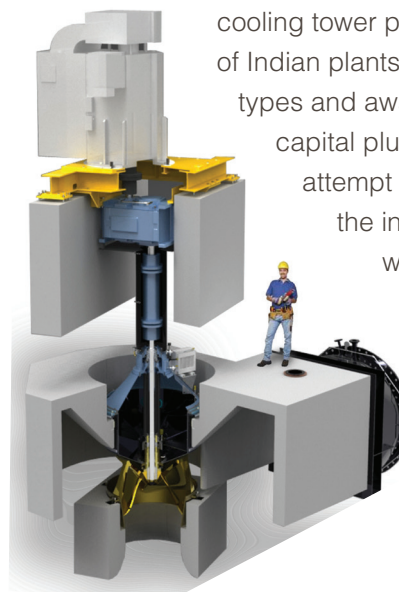
All thermal power plants reject large amounts of heat to the environment, and a conventional power plant is no exception. A typical ultra-supercritical, coal-fired power plant with a 45% thermal efficiency will reject 55% of the heat input by the fuel back into the environment. About 15% of this heat is rejected with the flue gases leaving the stack and by other miscellaneous heat losses in the plant. The balance of 40% is removed in the condenser by the condenser cooling water.

Condensers have traditionally been cooled with water using either once through or closed (cooling tower) systems. The cooling water flow requirements for an ultra-supercritical power plant are estimated to be 76 m<sup>3</sup>/hr per MW (335 US gpm per MW). This assumes a cooling water temperature rise of 10°C, which is appropriate for closed cooling systems. Cooling water temperature rise in seawater systems is usually limited to 7°C for environmental reasons, so flows could be expected to be 40% higher. As a result, our 600 MW reference plant using a cooling tower would require a total cooling water flow of about 50 200 m<sup>3</sup>/h (220 000 US gpm), allowing for a 10% margin. If the plant service water requirements are provided by the condenser cooling water pumps, this would have to be added to the flow required of these pumps.

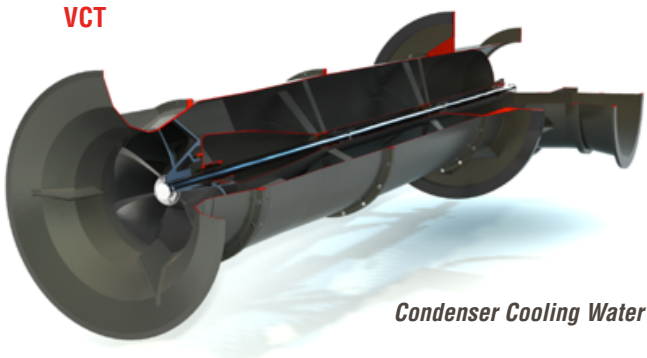
Flowserve can supply wet-pit vertical or concrete volute pumps for this application, depending upon customer requirements. In China, the industry has standardized wet-pit pumps for coal-fired plants, although concrete volute pumps are preferred in nuclear plants. This is simply because the pumps in nuclear plants are much larger than in conventional steam plants. In India, concrete volute pumps are usually preferred and specified on seawater-cooled plants and will likely also be specified on all 1000

MW plants as these are introduced into the market. On 660 and 800 MW cooling tower plants, the balance of Indian plants accept bids for both types and awards on the lowest capital plus power cost. No attempt is made to evaluate the installation costs, which can often be in favor of the CVPs.

#### BSV/BCV



#### VCT



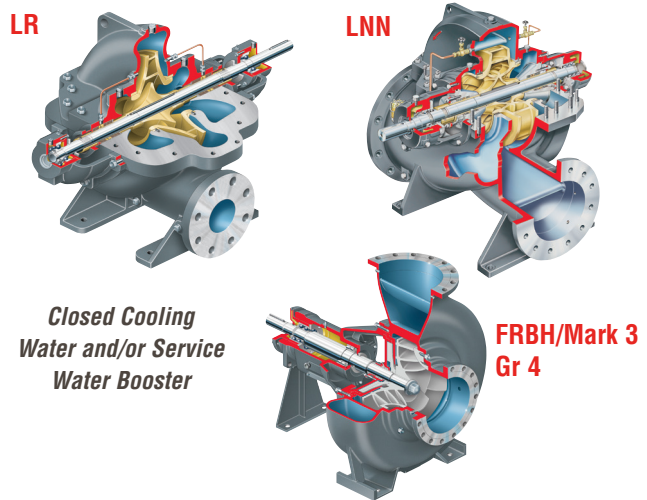
More plants are now using air-cooled condensers due to environmental considerations. This is particularly the case in China. A plant with a closed cooling water system still requires a continuous external supply of water for makeup. Cooling towers cool by evaporation; this results in the concentration of dissolved solids in the cooling water. As a result, blowdown and makeup of fresh cooling water are required. The initial capital cost of air-cooled condensers is much higher, and plant thermal efficiency may be reduced by as much as 3 or 4% in high ambient temperature locations. Nevertheless, tightening environmental legislation on power plant water intake and discharge will result in more new plants using air-cooled condensers.



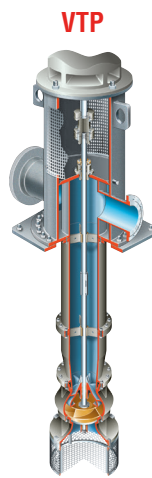
**Figure 7: One of five 62 APM circulating water pumps for a plant in Saudi Arabia**

**Closed Cooling Water Pumps (g)**

Power plants have a variety of equipment that must be cooled, including the main electric generator, boiler feed pump motors, pump seal and lube oil systems, and turbine lube oil systems. This cooling is provided by a closed cooling water system using demineralized water as the cooling medium. The closed cooling water pumps circulate the demineralized water through all of the cooling loads, and the heat is rejected in the plant cooling water system cooler. The total flow required for a typical 2x660 MW Indian power plant is 1800 to 2200 m<sup>3</sup>/h.



**Closed Cooling Water and/or Service Water Booster**



**Service Water**

Closed cooling water pumps may be horizontal axially split, double-suction or high-capacity end suction pumps, depending on the plant flow requirements and the customer's preference. Many customers prefer the end suction design because it is less costly and the nozzle configuration offers advantages in plant design. Others may prefer the more robust between bearings design.

Since this is a low-temperature and low-pressure clean water application, the pumps are normally cast iron with either carbon steel or 12% chrome impellers.

**Service Water Pumps (H)**

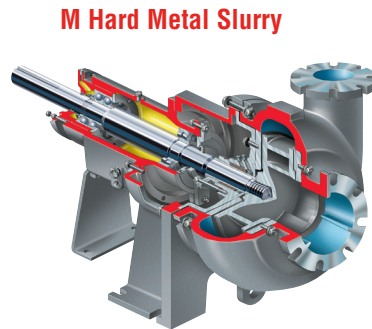
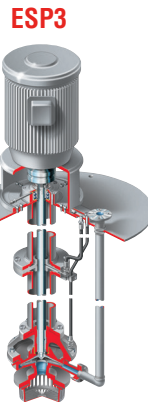
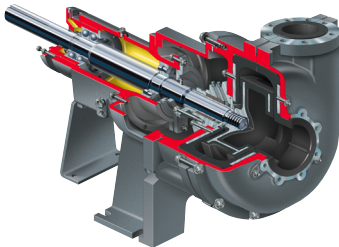
The heat rejected to the plant cooling water cooler is removed by service water from the cooling tower. This may be provided directly from the condenser cooling water pump discharge manifold. In such cases, a booster pump may be required. The service water flow required is approximately the same as the closed cooling water flow previously discussed. Horizontal end suction pumps or between bearings, single-stage pumps can be used for this application. Another arrangement is to use a separate set of vertical turbine pumps installed in the main condenser cooling water pump house.

**Miscellaneous Balance of Plant Pumps**

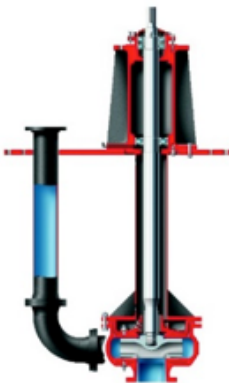
The following products are most typically used for miscellaneous services in water treatment, demineralized water and ash handling systems.



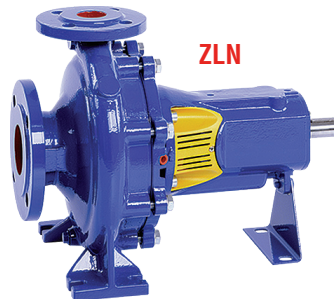
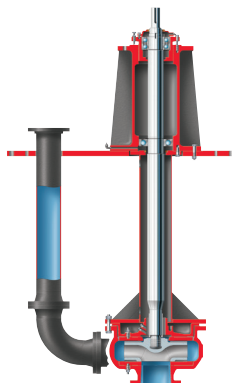
**R Rubber Lined Slurry**



**MJ Slurry**



**MJC Cantilever Slurry**



*Miscellaneous Applications*

## Valves for Conventional Steam Plants

A typical conventional coal-fired steam plant may have more than 5000 valves. The largest quantity of these are small-bore general service valves that cannot be covered in detail in this guide. The following section attempts to describe the major critical service valve applications in a conventional power plant. The item number after the application description refers to the location on the process flow diagram.

### Condensate Extraction Pump Recirculation Valve (1)

The condensate pump recirculation valve is intended to ensure the required minimum flow through the condensate pump to prevent excessive temperature rise, flow recirculation damage and hydraulic instability. Pump minimum flow requirements can vary from 20% to 30% of the best efficiency flow. There are typically 2x100% or 3x50% condensate pumps, and each one must have a dedicated recirculation valve. The downstream side of the valve is directed back to the condenser, but there is normally an orifice in the line to provide some back pressure on the valve. The downstream side of the valve is near saturation conditions at 38°C (100°F); the valve is thus subject to cavitation and flashing. The valve must provide tight shutoff when closed to avoid loss of thermal energy and seat damage.

**FLOWSERVE SOLUTION:** Valtek Mark One or Mark 100 with ChannelStream or DiamondBack anti-cavitation trim.

### Deaerator Level Control Valve (2)

The function of this valve is to control the water level in the deaerator during power plant load variations and also during startup and shutdown. During startup, the valve will see a low flow with a high-pressure drop because the pump generates more pressure at low flow and the deaerator has not built up full pressure. This can lead to severe cavitation, vibration and noise. During high flow, normal full load plant operation, it is desirable to minimize the pressure drop across the valve while providing accurate level control in the deaerator. In some cases, a smaller startup control valve may be provided, as illustrated in the process flow diagram.

**FLOWSERVE SOLUTION:** Valtek Mark One or Mark 100 with CavControl anti-cavitation trim.

### LP and HP Heater Drain Level Control Valves (3, 4)

The concept of feedwater heating was explained in an earlier section of the guide. In closed LP and HP heaters, steam extracted from the turbine gives up its energy to the feedwater and condenses and collects in the hotwell section of the feedwater heater. Heater drain or normal drain valves (3) are provided to accurately control the condensate level in the hotwell of each heater. During normal operation, condensate from each heater is cascaded to the next upstream feedwater heater. All the condensate collected from the LP heaters then flows back to the condenser or to the suction of the LP heater drain pump. The condensate from the HP heaters flows back to the deaerator. In all cases the condensate is at or near saturation conditions, so it has a tendency to flash as it passes from one heater to another.



In addition to the normal level control heater drain valves, the heater drain valve system includes emergency drain or dump valves (4). Emergency heater drain valves are utilized during upset conditions when the capacity of the normal level control valve is insufficient.

The most pressing issues in properly specifying heater drain control valves are flashing or cavitation, velocity, erosion and tight shutoff. Erosion is a function of the fluid velocity, and fluid velocity is a function of the percentage of fluid flashing to vapor. Pressure drops from heater to heater are usually less than 100 psi, but can be higher depending upon the plant design. The type and number of feedwater heaters also vary with each plant design.

The main differences between low- and high-pressure heater drain systems are the temperatures and pressures of the extraction steam and resulting condensate.

**FLOWSERVE SOLUTION:** Valtek Mark One or Mark 100 with CavControl anti-cavitation trim.

### Feedwater Control Valves (5)

The feedwater control system provides feedwater to the boiler at the required flow and pressure.

When a power plant is up and generating power, the feedwater control valve is operating under flow conditions not generally considered to be severe. During boiler fill and startup operations, however, the feedwater valve will experience conditions almost as severe as the feed pump recirculation control valve. A two-valve solution is often adopted

to best handle these two modes of operation. When two feedwater control valves are used, they are split-ranged, allowing the main feedwater valve to remain closed during startup operations when the pressure drop and cavitation potential are greatest. As the boiler comes on-line and more flow is required, the main feedwater valve will open to add necessary capacity. These two valves face different challenges.

The startup valve is subject to high-pressure drops and severe cavitation. Severe vibration is also possible, and the valve may be subject to erosion due to high fluid velocities. The valve needs to maintain tight shutoff when closed — under normal conditions for the reference plant — with low-pressure drop. Erosion from high fluid velocities and light cavitation may also occur. The main valve also must provide tight shutoff.

**FLOWSERVE SOLUTION:** Valtek Mark One or Mark 100 with CavControl anti-cavitation trim for the main valve and ChannelStream trim for the startup valve.

### Feed Pump Recirculation Valve (6)

As with the condensate extraction pump, each feedwater pump requires a recirculation valve to ensure the required minimum flow through the pump to prevent excessive temperature rise, flow recirculation damage and hydraulic instability. Minimum flow requirements can vary from 20% of the best efficiency flow of the pump to 40%, depending on the pump's design and energy level.

Older plants often used on/off control valves with backpressure orifices installed in the downstream line, but modulating globe valves are standard today. The modulating recirculation valve has to throttle through a wide range of flow with very high-pressure drop. The valve only operates during startup and shutdown and under very low plant

load conditions. During normal plant operation, the valve is closed and must provide the tightest shutoff possible.

During normal operation at full load, the valve remains closed and must seal tightly against a typical differential pressure. Any leakage will result in energy losses and damage to the trim. As a result, these valves are equipped with hardened metal seating surfaces of Class V sealing trim.

These valves are usually equipped with sophisticated anti-cavitation trim to handle the high differential pressures when the valve is modulating. A thorough understanding of the application and various operating conditions is essential to proper valve sizing.

An alternative approach is the automatic recirculation valve (ARV) offered by OEMs such as Schroeder, Shroedahl, Yarway and Hora. This is a self-actuated valve with an integral check valve. These valves have several disadvantages, including: higher pressure losses; mechanical linkages in the flow path that wear; leakage during normal operation when the valve is closed; and flow cannot not be monitored or flow settings altered during operation. These valves may be suitable in a small biomass or waste to energy plant under 50 MW, but they are seldom used in large power plants.

**FLOWSERVE SOLUTION:** Valtek Mark One or Mark 100 with ChannelStream and DiamondBack anti-cavitation trim.

### Deaerator Pegging Steam Valves (7)

As noted, the deaerator is as an open feedwater heater specially designed to remove non-condensable gases from the feedwater. Steam is supplied to the deaerator by the deaerator pegging steam valve for deaeration as well as to maintain the desired pressure in the vessel and thus to the suction of the main feedwater pump. Under normal operating conditions, the pegging steam is supplied from a suitable extraction point on the steam turbine. The process flow diagram shows an extraction midway through the IP section of the turbine. The pegging steam system usually includes two other pegging steam control valves. One provides steam from the auxiliary steam system for startup and another provides steam from the cold reheat line for low load operation (typically 15–40% load). These have not been shown in the figure for simplicity. The valves experience high exit velocities because of the volumetric expansion of the steam and can produce high noise if not properly selected.

**FLOWSERVE SOLUTION:** Valtek Mark One or Mark 100 with ChannelStream and DiamondBack anti-cavitation trim.

### Deaerator Steam and Condensate Blowdown Valves (8)

The deaerator is equipped with condensate and steam blowdown valves. The former directs flow to the liquid drain flash tank (LDFT) and the latter to the atmospheric flash tank (AFT).

**FLOWSERVE SOLUTION:** Edward Y-pattern globe blowoff valve; Edward angle pattern globe valves.

### Boiler Recirculation Control Valve (9)

The boiler recirculation pump is operated only during startup, low load and shutdown. The boiler recirculation system is equipped with a control valve to assure adequate circulation in the boiler during these conditions.

**FLOWSERVE SOLUTION:** Valtek Mark One or Mark 100.

### HP and LP Turbine Bypass Valves (10)

These valves are special steam-conditioning valves used to bypass steam in the event of a steam turbine trip without having to shut down the boiler. They also ensure that critical turbine components are not subjected to temperatures that would be harmful. The turbine bypass system allows power plants to start more quickly and handle rapid load variations. These specialized valves control both pressure and temperature. Flowserve does not have a product offering for this application; however, Flowserve can offer the associated turbine bypass spray valves (see below).

### HP and LP Turbine Bypass Spray Water Valves (11)

These spray water valves provide water to the steam-conditioning bypass valves. The water for the HP bypass is provided by the main feedwater pump, while the supply for the LP bypass is provided by the condensate extraction pump. The valves must provide accurate control and tight shutoff. High-pressure drops may be expected and can cause cavitation.

**FLOWSERVE SOLUTION:** Valtek Mark One with CavControl or SideWinder anti-cavitation trim.

### Super Heater and Reheater Attemperator Spray Valves (12)

Attemperators are used to control the temperature of superheated steam going to the steam turbine by injecting feedwater or condensate through nozzles in the steam line. The attemperator nozzles are designed to ensure complete mixing and rapid vaporization of the spray water. Attemperators are normally located between the primary and secondary superheaters and between the primary and secondary reheaters. Accurate control is essential to protect the turbine from overheating without impairing plant efficiency or allowing water droplets to form, which might cause damage to turbine blades.

Attemperator spray valves control the flow of water to attemperators. These valves require high rangeability, tight shutoff (Class V) and must provide long service life. Water for desuperheating superheater steam is supplied from the main discharge of the feed pumps. A special inter-stage takeoff on the feed pump supplies the spray water for the reheater attemperator.

**FLOWSERVE SOLUTION:** Valtek Mark One with CavControl or SideWinder anti-cavitation trim.

### Steam Turbine Extraction Steam Valves (13)

The heating medium for the low- and high-pressure feedwater heaters and the deaerator is extraction steam supplied by the turbine. The points of steam extraction are selected to match the temperature requirements of the heaters.

Each extraction line typically has a tight closure triple-offset butterfly valve as well as a stop-check and non-return valve, though the configuration may vary from heater to heater. Additional motorized on/off valves may be needed in the case where there are parallel trains of heaters, as is normally the case with the HP heaters. Additional quick acting stop-check valves may be required in the case of the deaerator where the supply steam comes from multiple sources during different operating modes (see pegging steam valves above).

**FLOWSERVE SOLUTION:** Control valve: Durco TX3 triple-offset butterfly valves. Non-return valve: Edward Flite-Flow® Y-pattern globe valve and Edward Univalve Y-globe. Stop valve: Edward Equiwedge gate valve.

### Condenser Cooling Water System Butterfly Valves (14, 15, 17)

Generally, a quick-opening, double-offset butterfly valve (14) is used on the discharge of each cooling water pump. These remain wide open during normal operation, with the pump riding on the system curve without any attempt to control the flow. The reference plant total cooling water flow requirement be shared between two or among three pumps.

Most power plant projects consist of multiple power units, with a cooling tower for each unit. However, the cooling water pumps are installed in a common pump house and may feed a common header. As a result, on/off butterfly valves are needed to isolate the cooling towers (17). Isolation valves are also provided on each condenser water box (15).

In seawater applications, the valves would need to be made of duplex or super-duplex.

**FLOWSERVE SOLUTION:** Valdisk double-offset BX butterfly valves.

### Plant Equipment Cooling Water System Valves (16)

A closed cooling water system using demineralized water meets the cooling needs of all of the equipment in the plant. The heat sink for this cooling system is the plant heat exchanger, which is cooled by clarified water from the cooling tower basin. This water may be supplied by dedicated service water pumps in the basin or from a takeoff line from the discharge of the main condenser cooling water pumps. The valve construction would be similar to what is provided for the condenser cooling pumps, but would have a much smaller diameter.

**FLOWSERVE SOLUTION:** Valdisk double-offset BX butterfly valves.

**Equipment Block and Bypass Check Valves**

Most of the control valves indicated in the process flow diagram and discussed herein are equipped with upstream and downstream isolation or block valves as well as a bypass valve. These valves require tight shutoff. The isolation valves, which are

normally open, need to allow full flow with minimum pressure drop; gate valves are the preferred option for these applications.

**FLOWSERVE SOLUTION:** Edward Equiwedge gate valves; Edward Flite-Flow globe valves; Edward tilting disc check valves.

**The following Flowserve products apply to most of the on-off applications discussed herein:**

**EDWARD  
BLOWOFF  
Y-PATTERN  
GLOBE VALVES**

**EDWARD  
ANGLE PATTERN  
BLOWDOWN  
GLOBE VALVES**

**EDWARD  
Y-PATTERN  
FLITE-FLOW  
GLOBE VALVES**

**EDWARD  
EQUIWEDGE  
GATE VALVES**

**EDWARD  
TILTING DISC  
CHECK VALVES**



**VALDISK BX  
DOUBLE-OFFSET  
BUTTERFLY**

**DURCO TX3  
TRIPLE-OFFSET  
BUTTERFLY**



The following Flowserve products handle the majority of control valve applications noted:

VALTEK  
MARK ONE



VALTEK  
MARK TWO



VALTEK  
MARK 100



VALTEK  
MARK 200



## Actuators for Conventional Steam Plants

Many of the Edward multi-turn globe and gate valves and their related applications as described herein would use electrical instead of manual actuation, as pictured. Flowserve offers an extensive range of electrical actuators for these applications. For example, the Flowserve Limatorque MX non-intrusive, multi-turn actuator. These provide a comprehensive network option portfolio to users, including Foundation Fieldbus, HART and DeviceNet.

The QX quarter-turn actuator would be used for any quarter-turn applications (e.g., ball valves).

On new projects, the actuators are normally purchased with the valves and not directly by the EPC or OEM.

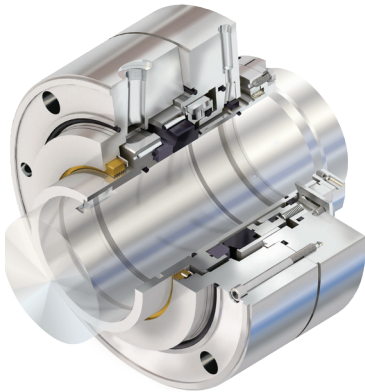
Limatorque MX



*Non-intrusive Electric Actuators*

## Seals for Conventional Power Plants

Flowserve has a full range of seal products to cover all pump applications in a conventional power plant. The most challenging application in supercritical and ultra-supercritical power plants is the main feed water pump, which is a large shaft, high-speed, high-energy pump. The Flowserve default offering on this application is a controlled leakage bushing seal, but more customers are specifying mechanical seals.



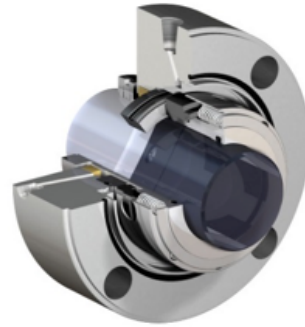
### DHTW Series Pusher Seals for Boiler Feed

Available with precision face topography and other features ideally suited to supercritical and ultra-supercritical feed pump applications where ultrapure, low conductivity feedwater can lead to electrically induced corrosion.

The DHTW is a custom engineered seal specifically for the application.

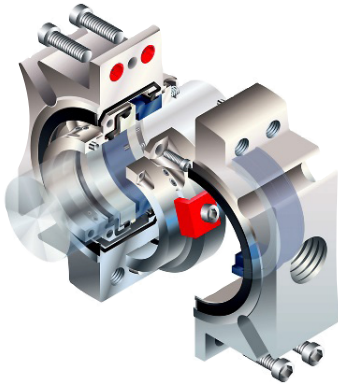
The QB seal is the preferred solution for condensate extraction, heater drain, and for main or standby feedwater pumps in smaller subcritical power plants. Condenser cooling water and service water pumps typically use packing, but the PSSL III split seal is an ideal mechanical sealing option. It offers improved housekeeping and safety compared to packing due to its significantly lower leakage. When the distance between shaft ends (DBSE) in vertical pumps is too small to allow the use of a cartridge seal, the PSSL split seal can be installed without disturbing the pump's motor.

Most other applications in a conventional power plant can be handled with the ISC2 family of products.



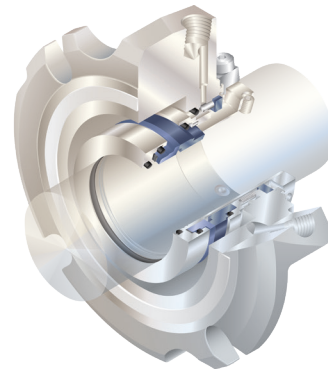
### QB Series Balanced Pusher Seals for Boiler Feed and Condensate Extraction

Boiler feed and recirculation applications are typically provided with Plan 23 seal flush systems. Condensate extraction applications are provided with Plan 13 and 32.



**PSS III Split Seal for CCW and Service Water**

Vertical wet-pit condenser circulating water and service water pumps with packing can be easily upgraded with this split-seal design. Split seals are ideally suited to large, low-pressure pumps, which typically have high in-and-out costs, making traditional non-split mechanical seals unattractive.



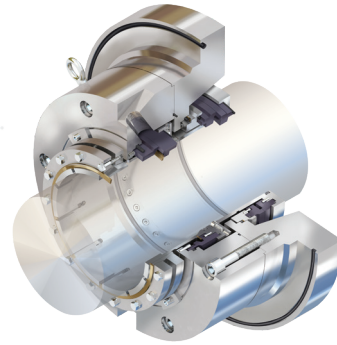
**ISC2-PX Standard Cartridge Pusher Seals for General Service Applications**

The ISC2 is the first choice for miscellaneous sealing applications such as closed cooling water, demineralized water, screen wash, service water, etc.



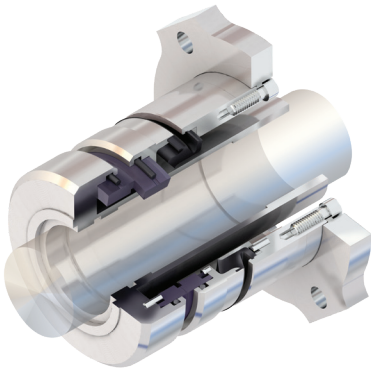
## Seals for Wet Limestone Flue Gas Desulfurization

Flowsolve is a leader in the supply of seals for wet limestone flue gas desulfurization pump applications. The default selections for most applications are RIS, SLM or SLC single seals with Plan 03. The large absorber recirculation pumps handle aerated slurry and can collect air in the seal chambers. In these cases, a Plan 62 water quench or Plan 32 is recommended; in some situations, a dual seal with Plan 62 or 32 may be necessary. Custom SLM-6000 (single seal) and SLM-6200 (dual seal) designs are available for applications.



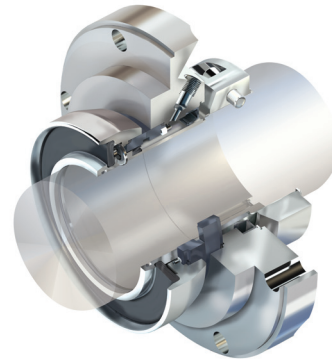
### SLM Series

Single and dual cartridge seals available with flush, quench and drain options and design customization as required. SLM seals utilize a multiple-coil spring flexible element, which is isolated from the process by the position of the dynamic O-ring. This keeps the springs clean and reduces the chances for clogging or hang-up.



### RIS

RIS seals are uniquely mounted directly to the pump's bearing housing so that the seal moves along with the impeller, bearing housing and shaft assembly during impeller adjustments. RIS seals are also externally adjustable to compensate for seal face wear and pump misalignment. A unique feature of the RIS seal is its rubber is a shear flexible element, impervious to clogging and hang-up.



### SLC Series

The SLC is the first choice cartridge slurry seal in its size range. The cone spring flexible element cannot be clogged or hung-up, which completely eliminates a failure mode common in slurry seals.

## Innovative Ways Flowserve Addresses Customer Challenges

<p><b>EXPERTISE AND EXPERIENCE</b></p>	<ul style="list-style-type: none"> <li>• Flowserve has more than 80 years of experience in the power industry and has been a key supplier of pumps, valves and seals for conventional steam power plants since the beginning of the conventional steam era.</li> <li>• Flowserve has one of the largest installed bases of pumps and valves in critical conventional steam applications around the world.</li> <li>• Specialist “Virtual Centers of Excellence” ensure that expertise acquired over multiple products and manufacturing sites is shared across the global Flowserve organization.</li> </ul>
<p><b>SINGLE-SOURCE PROVIDER</b></p>	<ul style="list-style-type: none"> <li>• Flowserve offers a full range of pumps, valves and seals for the conventional steam market, simplifying the procurement process for our customers.</li> <li>• Global commercial operations organization ensures knowledgeable and professional review and response to customer RFQs, including those with the most complicated technical requirements.</li> </ul>
<p><b>STREAMLINED EXECUTION</b></p>	<ul style="list-style-type: none"> <li>• Each Flowserve factory has efficient and professional project management organizations to ensure on-time completion of projects to customer requirements.</li> <li>• Where projects involve multiple Flowserve manufacturing locations, global project managers can be provided to coordinate order fulfillment. This ensures fewer errors and delays and simplifies communications between Flowserve and the customer.</li> </ul>
<p><b>LOCAL SUPPORT WORLDWIDE</b></p>	<ul style="list-style-type: none"> <li>• A large field service organization ensures technicians are available for installation, commissioning and troubleshooting without delay.</li> <li>• Service and maintenance contracts for highest availability and continuous efficiency optimization can be tailored to customer needs.</li> <li>• A global network of Flowserve Quick Response Centers (QRCs) means that local service and repair are always available.</li> <li>• Product upgrades are continuously being introduced to improve the performance and reliability of Flowserve products in the field.</li> <li>• Full operation and maintenance training are available to end users.</li> <li>• Equipment monitoring programs are also available.</li> </ul>
<p><b>OPTIMIZED EFFICIENCY</b></p>	<ul style="list-style-type: none"> <li>• The close Flowserve involvement with the conventional steam market has provided the industry feedback needed to develop the range of hydraulics best suited to customer requirements, ensuring the best and most efficient selections are always available.</li> <li>• As one of the largest engineered pump manufacturers in the world, the Flowserve hydraulic engineering capabilities and resources are second to none. Flowserve is able to provide pumping equipment that consumes the least amount of power.</li> </ul>

## APPENDIX

## Flowserve Value Proposition in Conventional Steam

FLOWSERVE	VALUE	CUSTOMER BENEFIT
Ethical business practices	Flowserve sets the highest standards in business integrity in its dealings with suppliers and customers.	A trustworthy partner to work toward their project success
Quality	Flowserve manufactures to the most rigorous quality standards to provide reliable products.	Satisfaction in supplier choice, on-time commissioning and project startup
Engineering excellence	The Flowserve depth of engineering experience is unparalleled in conventional steam power plants.	Optimized product and material selection for each application ensures reliable operation.
Experience	Flowserve has been a leader since the process was commercialized on a large scale.	Lessons learnt have been built into today's products, increasing reliability, maintainability and product life.
Broad product range	Flowserve comprises a list of world-renowned heritage brands and a wide portfolio of products and services.	A product for every service designed by specialists in their respective fields ensures low-cost, high-efficiency solutions.
Project management	Dedicated project managers certified by IPMA	Professional team to handle documentation and ensure on-time delivery
After-sales support	Dedicated after-sales support engineers	Implanted within project management, with the sole objective to resolve warranty issues quickly and painlessly
Local Quick Response Centers	Fully equipped Quick Response Centers in the region	Skilled team to handle upgrades and repairs; localized to reduce downtime, full access to Flowserve component drawings, procedures and standards
Aftermarket solutions	Long-term maintenance	Specialist group capable of maintaining, servicing and upgrading equipment to meet operating goals throughput
Safety	Considerable experience and pioneer in power industry; with product designs considering industry standards and low-risk design factors and maintainability	Maximize MTBF, ease of monitoring equipment

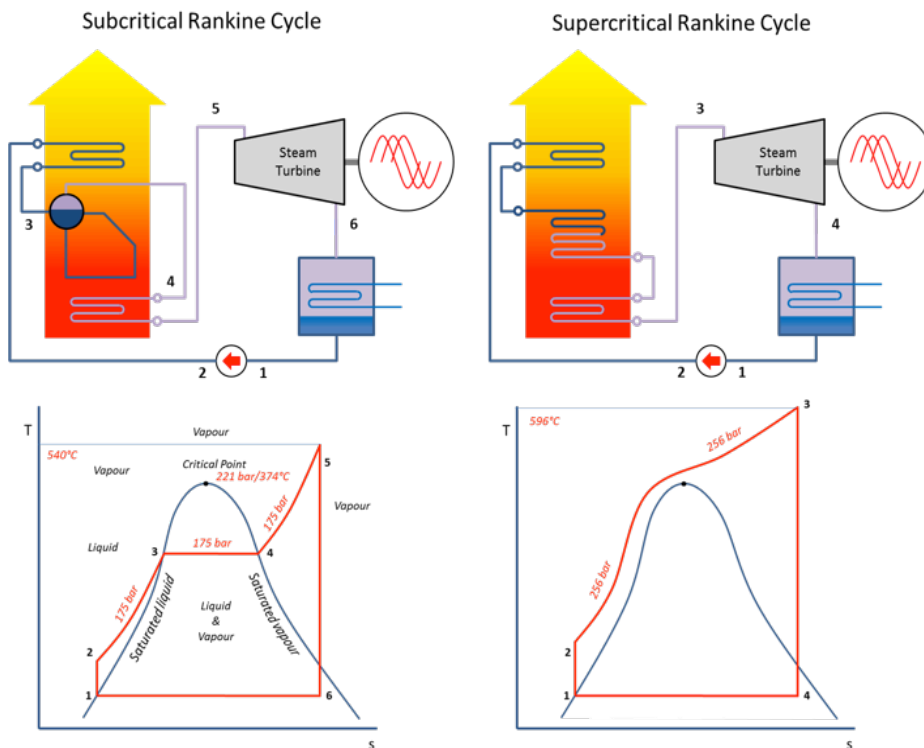
## Sub-critical Versus Supercritical Power Plant

Everyone is well aware that water in an open container boils at 100°C (212°F) when at sea level. Both liquid and vapor exist at the same temperature while boiling. The same is true in a conventional subcritical boiler, where the water and steam are pressurized. Once the water is brought to the boiling point in the economizer (2–3 left T–S diagram), it begins to boil in the evaporator. The liquid and vapor coexist in the steam drum, and the liquid recirculates through the evaporator tubes to continue boiling (3–4). The steam produced then goes to the superheater where it is heated well above saturation (4–5) before it is expanded in the steam turbine (5–6).

However, water behaves differently above its critical point of 221 bar (3204 psia). There is no distinct boiling phase under these conditions, and the water is continuously transformed as a homogeneous fluid

into steam as the temperature rises in the boiler (2–3 right T–S diagram). Plants that operate above the critical point are called *supercritical power plants*.

The higher steam temperature of a supercritical plant results in higher thermal efficiency and lower fuel consumption for a given power rating. The best subcritical power plants can achieve thermal efficiencies of up to 38%, while supercritical plants can achieve efficiencies of 42–43%. Ultra-supercritical power plants operating at temperatures up to 620°C (1148°F) achieve efficiencies of 45%. While there is no universally accepted definition, plants operating above 600°C (1112°F) are typically described as being *ultra-supercritical*. Advanced USC plants are under development and will push pressures to 300 to 350 bar and 700 to 760°C (4350 to 5075 psia and 1292 to 1400°F).



## Reheat

Reheat is used to improve the overall thermodynamic performance of the plant. Raising the operating pressure of the boiler without using reheat leads to problems with condensation, forming the later stages of the steam turbine. Without reheat, the steam turbine exhaust conditions below would be at point 4'. The weight percentage of liquid in the exhaust would be equal to  $b/(a+b)$ . By reheating the steam between the HP and IP turbine sections, the fraction of liquid in the exhaust can be dramatically reduced. It should also be noted that the area inside the red lines is proportional to the power produced, so the total power of the plant is also enhanced.

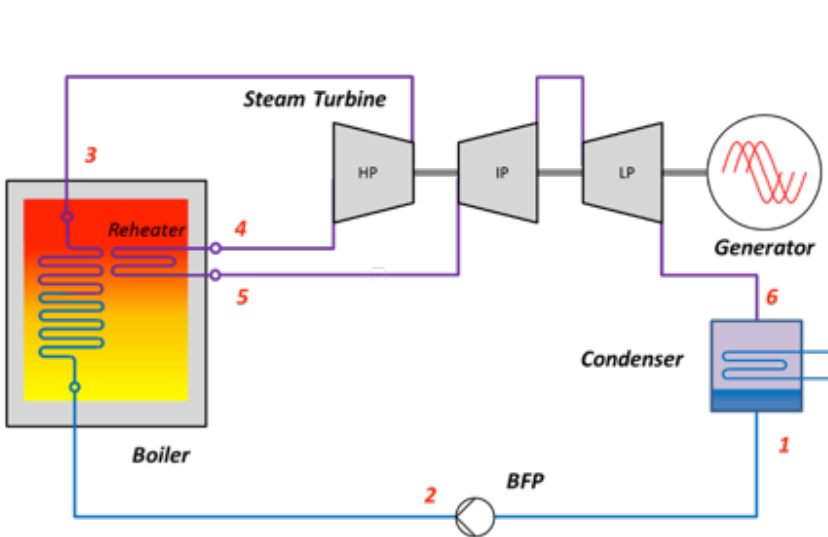
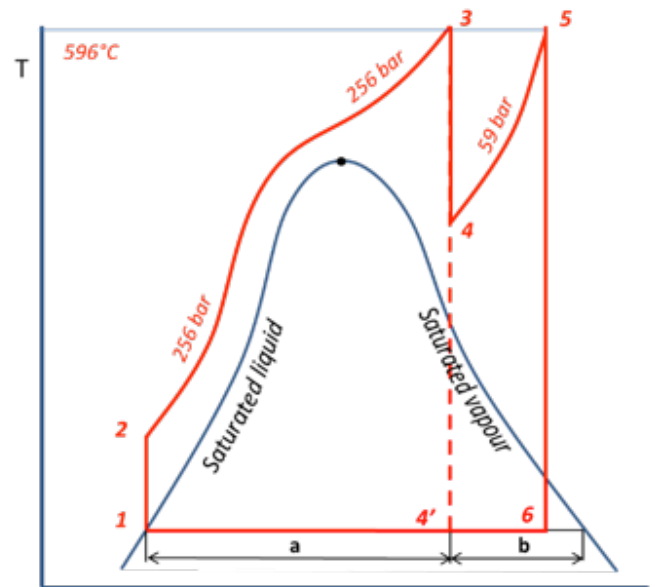


Figure 8: Illustration of the use of reheat in supercritical plants



# GLOSSARY OF KEY TERMS, ABBREVIATIONS AND ACRONYMS

## Terminology

**Attemperator:** a device for reducing the temperature of superheated steam by spraying water through nozzles into the steam line.

**Availability:** The percentage of the hours in the year that the plant was operating or available to operate.

**Benson boiler:** an evaporator design that does not require a steam drum. Feedwater enters one end of the boiler and steam comes out the other end without any separation or recirculation. Originally a license of Siemens.

**Capacity factor:** The total kWh generated in a year divided by the plant nameplate net rating in kW times 8760 hours.

**Gigawatt (GW):** 1000 megawatts.

**Kilowatt (kW):** a unit of power (work done per unit time). A kilowatt is 1000 watts.

**Megawatt (MW):** 1000 kilowatts. One megawatt is sufficient to provide the electricity needs of 600 to 900 homes in the developed world. Plants are typically rated in MW.

**Overnight cost:** the cost of a construction project if no interest was incurred during construction, as if the project was completed “overnight.”

## GLOSSARY OF KEY TERMS, ABBREVIATIONS AND ACRONYMS – CONTINUED

### Acronyms

**AFT:** atmospheric flash tank

**ARV:** automatic recirculating valve

**BFP:** boiler feedwater pump

**BTG vendor:** boiler and turbine-generator vendor

**CCS:** carbon capture and storage

**CCW:** condenser cooling water, as in CCW pump

**CEP:** condensate extraction pump

**CSP:** concentrated solar plants

**DBSE:** distance between shaft ends

**DI:** design institute

**EPC:** engineer, procure and construct

**HFO:** heavy fuel oils

**HP:** high-pressure

**ESP:** electrostatic precipitator

**FGD:** flue gas desulfurization

**HRSG:** heat recovery steam generator

**ID:** induced draft

**IEA:** International Energy Agency

**IGCC:** integrated gasification combined cycle

**IPP:** independent power plant

**LDFT:** liquid drain flash tank

**LP:** low-pressure

**LSTK:** lump sum turnkey

**MCR:** maximum continuous rating

**MWe:** megawatt electric (the electrical power output of the generator)

**MWt:** megawatt thermal (the thermal power output of the boiler)

**NPSHA:** net positive suction head available

**OECD:** Organization for Economic Cooperation and Development (the world's most developed countries)

**OEM:** original equipment manufacturer

**PPA:** Purchase Power Agreement

**SCR:** selective catalytic reduction

**SWFGD:** seawater flue gas desulfurization

**T-G set:** turbine generator set

**USC:** ultra-supercritical

**VWO:** valve wide open



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