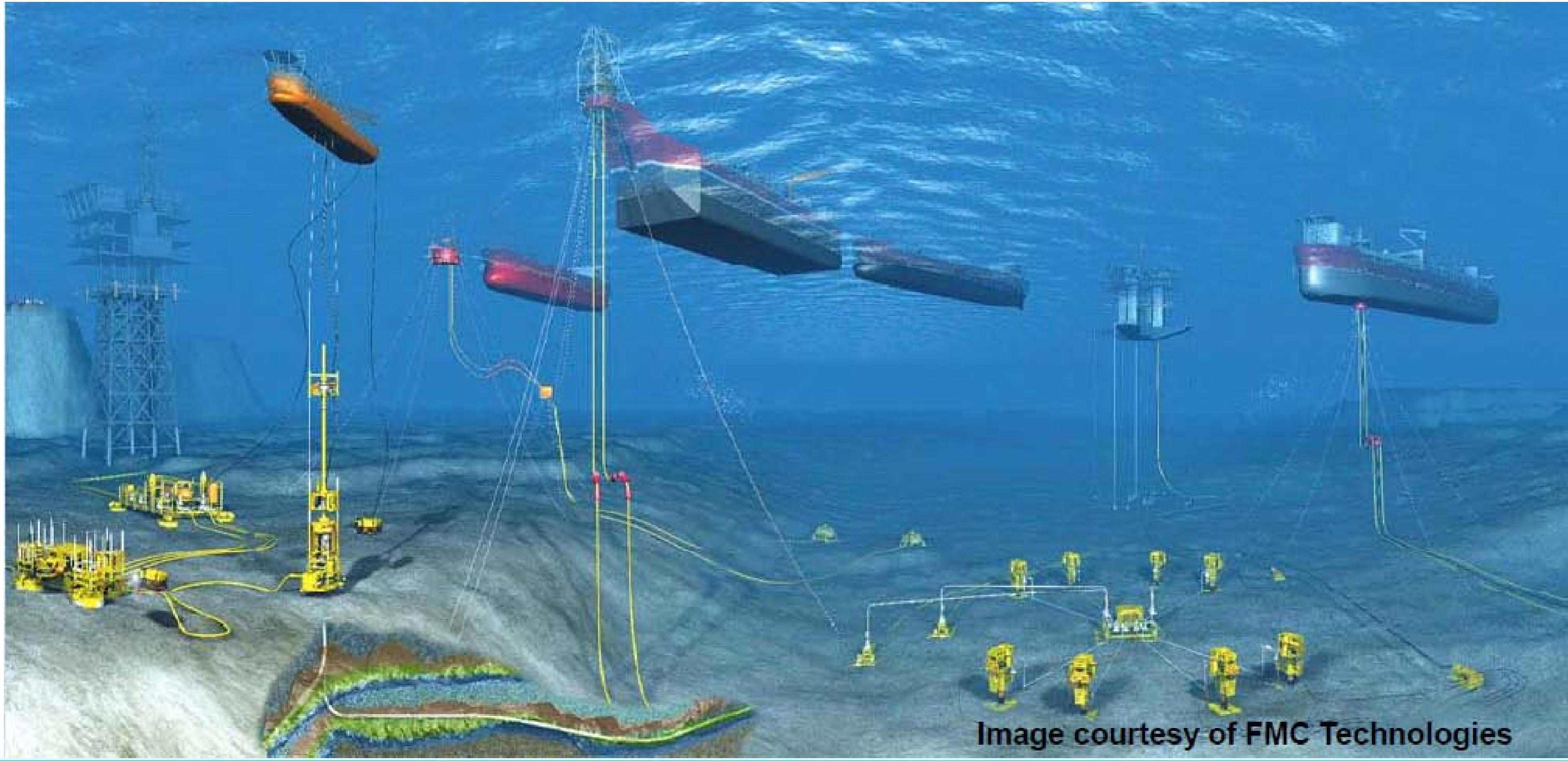


해양 자원 개발 시스템 개론
: Introduction to Offshore Petroleum Production System

Yutaek Seo

Period	Contents
1 Week	General introduction, outline, goals, and definition
2 Week	Type of reservoir fluids : Dry gas / Wet gas / Gas condensate / Volatile oil / Black oil PVT laboratory testing : Constant mass expansion / Differential vaporization / Compositional analysis / : Oil densities and viscosity / SARA, Asphaltenes, WAT
3 Week	Fluid sampling and characterization : Bottom hole samples / Drill stem test samples / Case studies
4-5 Week	Thermodynamics and phase behavior : Ideal gas / Peng-Robinson (PR) / Soave-Redlich-Kwong (SRK) : Peneloux liquid density correction / Mixtures / Properties calculated from EoS
6 Week	Subsea Field Development : Field configuration / Artificial rift / Well layout
7 Week	**Well components** **: Well structures/Christmas tree**
8 Week	Subsea manifolds/PLEM and subsea connections : Components / design / installation
9 Week	Umbilical / risers / flowlines : Design criteria/ analysis
10 Week	Flow regime : Horizontal and vertical flow / Stratified flow / Annular flow / Dispersed bubble flow / Slug flow
11 Week	Flowline pressure drop : Frictional losses / Elevation losses / Acceleration losses / Errors in ΔP calculation / Pipe wall roughness
12 Week	Liquid hold up : Cause / Prediction / Field & experimental data / Three phase flow
13 Week	Flow assurance issues : Hydrate/Wax/Asphaltene/Corrosion/Scale
14 Week	Field operation : Operational procedures for offshore petroleum production
15 Week	Application Example: Offshore platform (Pluto fields), Floating production system (Ichthys fields)
16 Week	Final Test

Subsea tree

- Function requirement

: Direct the produced fluid from the well to the flowline (called production tree) or to canalize the injection of water or gas into the formation (called injection tree).

: Regulate the fluid flow through a choke (not always mandatory).

: Monitor well parameters at the level of the tree, such as well pressure, annulus pressure, temperature, sand detection, etc.

:Safely stop the flow of fluid produced or injected by means of valves actuated by a control system.

: Inject into the well or the flowline protection fluids, such as inhibitors for corrosion or hydrate prevention.

Well head

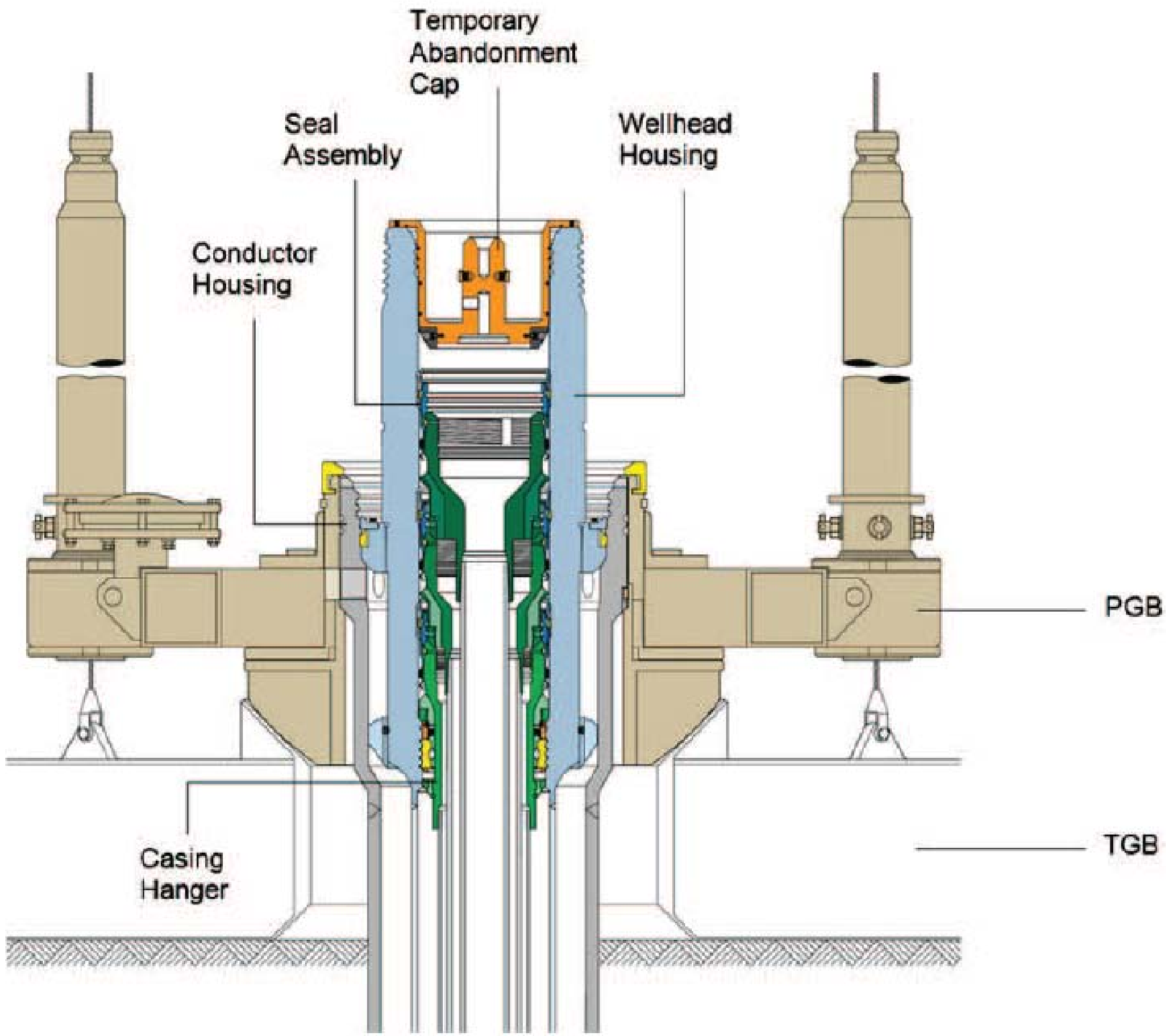
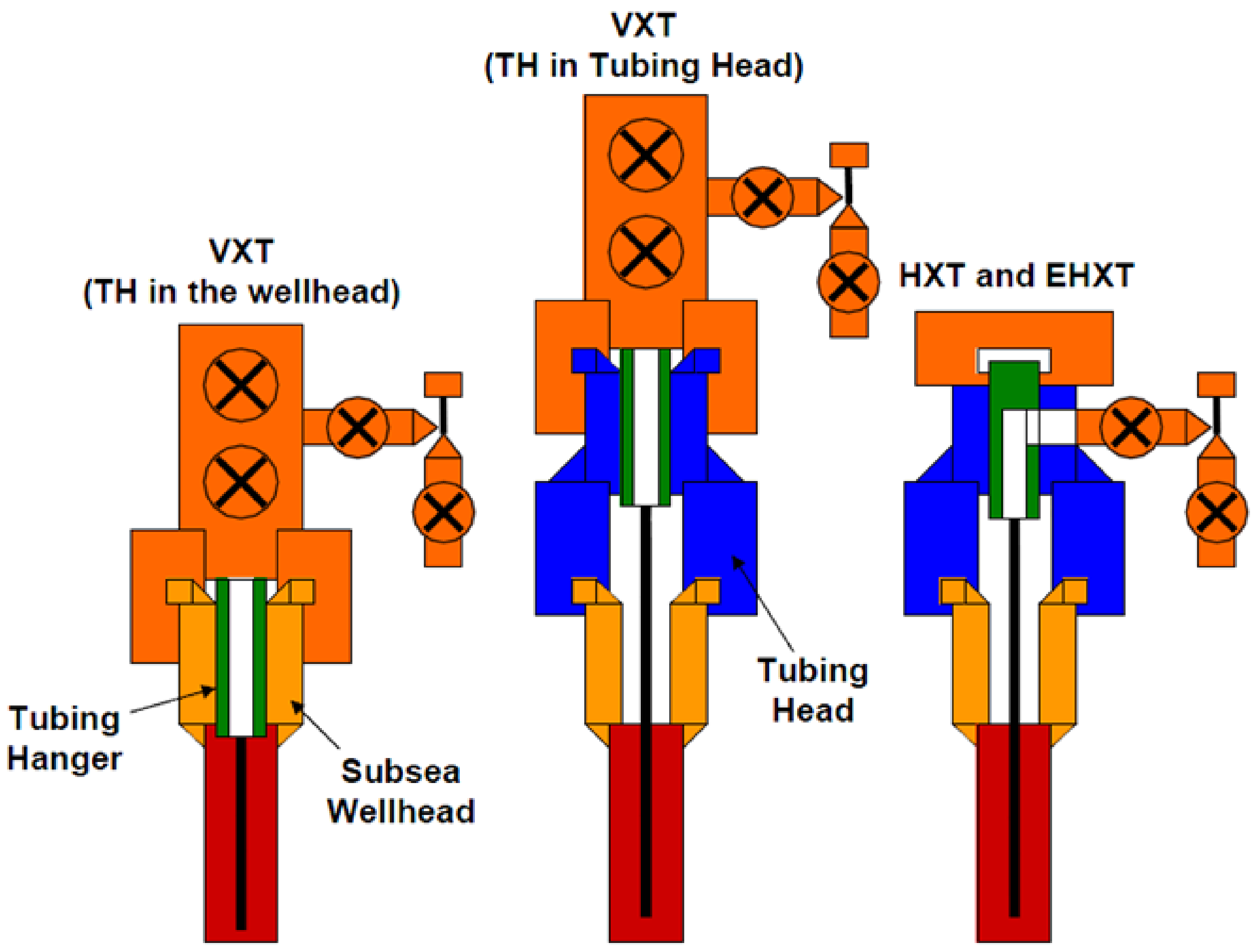


Figure 22-5 Typical $18^3/_4$-in.Subsea Wellhead System *(Courtesy of Dril-Quip)*

Subsea trees

Mudline Tree



Vertical Xmass Tree

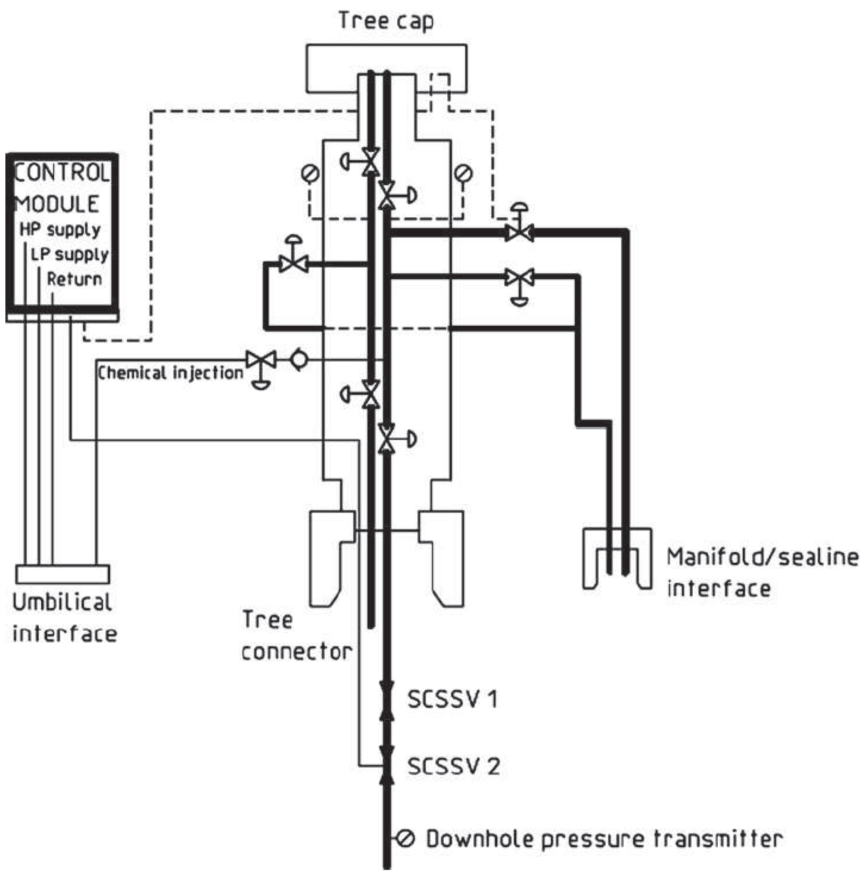
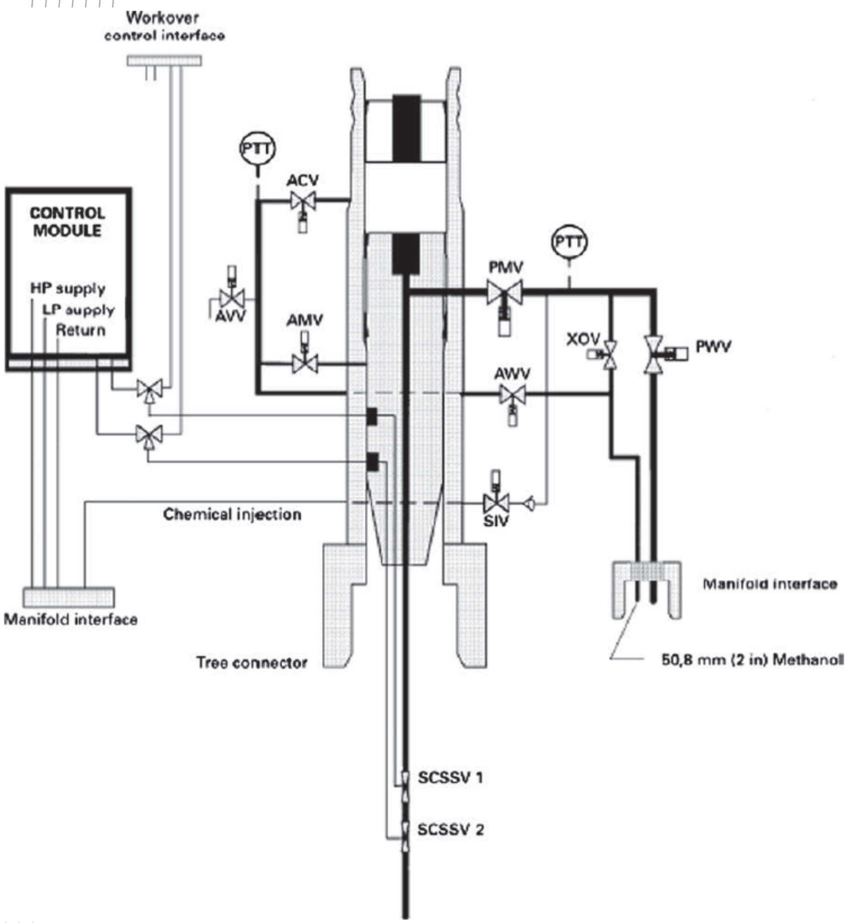


Figure 22-15 Schematic of Vertical Xmas Tree *(Courtesy of API RP 17A)*

- The master valves are configured above the tubing hanger in the vertical Xmas tree (VXT).
- VXTs are applied commonly and widely in subsea fields due to their flexibility of installation and operation.
- The production and annulus bore pass vertically through the tree body of the tree. Master valves and swab valves are also stacked vertically.
- The tubing hanger lands in the wellhead, thus the subsea tree can be recovered without having to recover the downhole completion.

Horizontal Xmass Tree



- The valves are mounted on the lateral sides, allowing for simple well intervention and tubing recovery.
- This concept is especially beneficial for wells that need a high number of interventions.
- Swab valves are not used in the HXT since they have electrical submersible pumps applications.
- The key feature of the HXT is that the tubing hanger is installed in the tree body instead of the wellhead.
- This arrangement requires the tree to be installed onto the wellhead before completion of the well.

Figure 22-14 Xmas Vertical Tree *(Courtesy of FMC)*

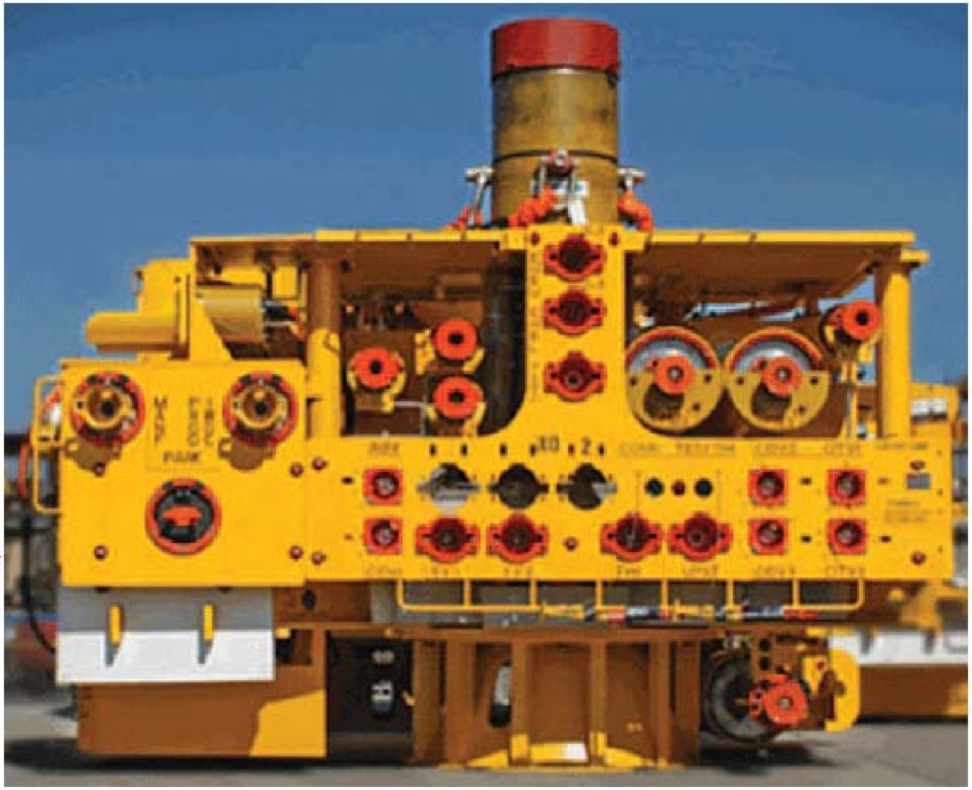


Figure 22-16 Horizontal Xmas Tree *(Courtesy of FMC)*

Selection criteria

- The cost of an HXT is much higher than that of a VXT; typically the purchase price of an HXT is five to seven times more.
- A VXT is larger and heavier, which should be considered if the installation area of the rig is limited.
- Completion of the well is another factor in selecting an HXTor VXT. If the well is completed but the tree has not yet been prepared, a VXT is needed. Or if an HXT is desired, then the well must be completed after installation of the tree.
- An HXT is applied in complex reservoirs or those needing frequent workovers that require tubing retrieval, whereas a VXT is often chosen for simple reservoirs or when the frequency of tubing retrieval workovers is low.
- An HXT is not recommended for use in a gas field because interventions are rarely needed.

Design process

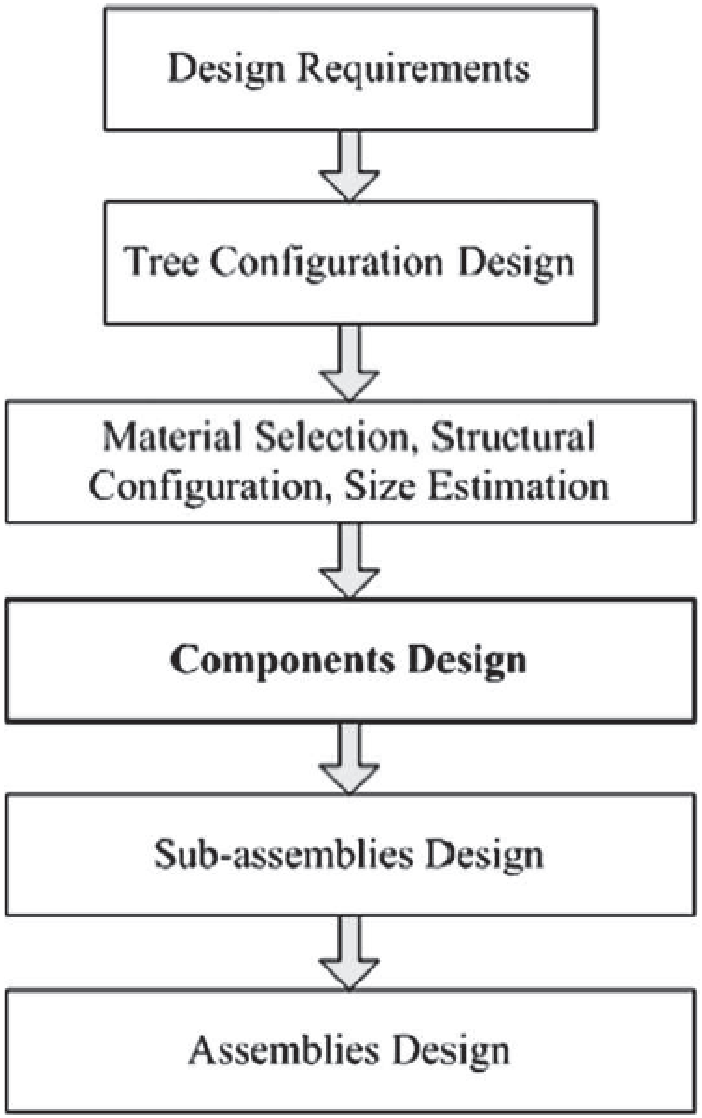


Figure 22-18 Design Process of Subsea Xmas Tree

Design requirement

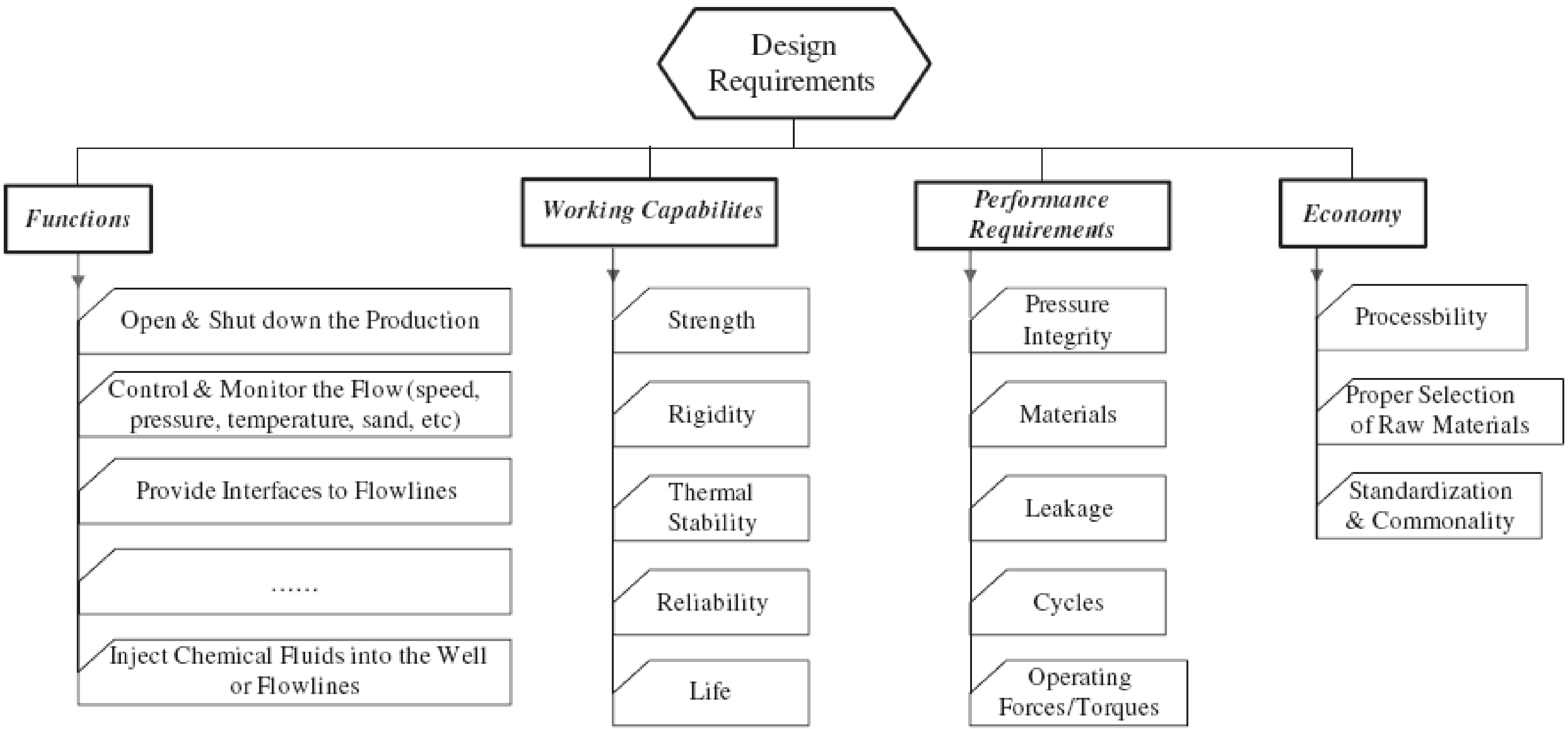


Figure 22-19 Design Requirements

Tree configuration

- After the functions and requirements are clearly known by the designer, the tree type can be determined and the schematic diagram drawn.
- Draft structural drawings of the tree are usually done during this phase.

Component design

- Tubing hanger system;
- A tree connector to attach the tree to the subsea wellhead;
- The tree body, a heavy forging with production flow paths, designed for pressure containment. Annulus flow paths may also be included in the tree body;
- Tree valves for the production bore, the annulus, and ancillary functions. The tree valves may be integral with the tree body or bolted on;
- Valve actuators for remotely opening and closing the valves. Some valves may be manual and will include ROV interfaces for deep water;
- Control junction plates for umbilical control hook-up;

- Control system, including the valve actuator command system and pressure and temperature transducers. The valve actuator command system can be simple tubing or a complex system including a computer and electrical solenoids depending on the application;
- Choke (optional) for regulating the production flow rate;
- Tree piping for conducting production fluids, crossover between the production bore and the annulus, chemical injection, hydraulic controls, etc.;
- Tree guide frame for supporting the tree piping and ancillary equipment and for providing guidance for installation and intervention;
- External tree cap for protecting the upper tree connector and the tree itself. The tree cap often incorporates dropped object protection or fishing trawler protection.

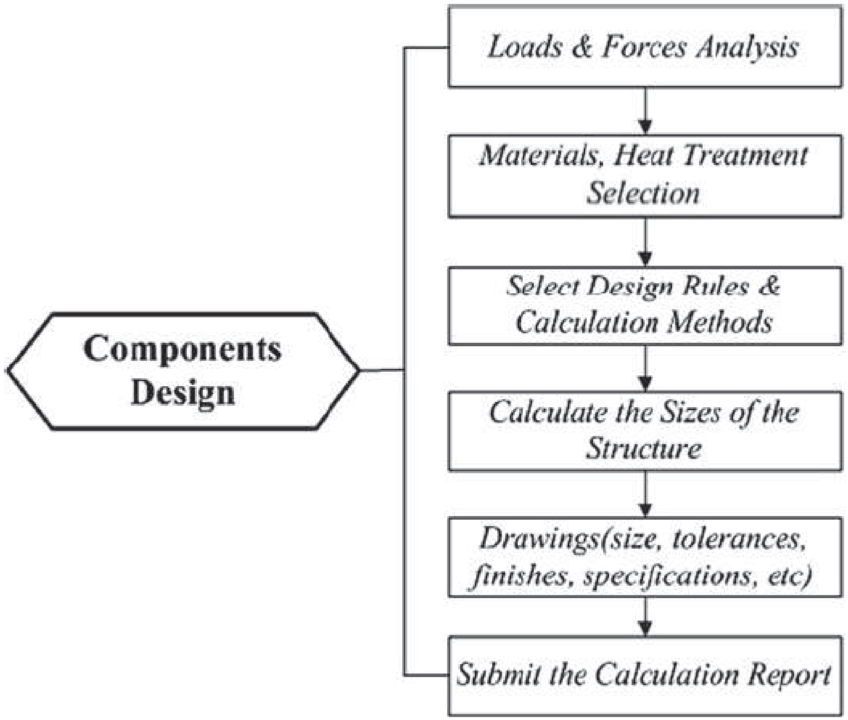


Figure 22-20 Component Design Process

- Subassembly and assembly design includes a report that shows the assembly procedures and the assembly drawings.

Service conditions

- Pressure ratings of subsea Xmas trees are standardized to 5000 psi (34.5MPa), 10,000 psi (69.0 MPa), and 15,000 psi (103.5 Mpa). Recently20,000-psi (138-Mpa) subsea trees have been applied successfully in subsea fields.
- Subsea equipment should be designed and rated to operate throughout a temperature range of 35 to 250ºF according to the API Specification 17D.

Table 22-3 Material Class Rating [2]

Retained Fluids	Relative Corrosivity of Retained Fluid	Partial Pressure of CO_2 (psia) (MPa)	Recommended Material Class
General service	Noncorrosive	<7 (0.05)	AA
General service	Slightly corrosive	7 to 30 (0.05 to 0.21)	BB
General service	Moderately to highly corrosive	>30 (0.21)	CC
Sour service	Noncorrosive	<7 (0.05)	DD
Sour service	Slightly corrosive	7 to 30 (0.05 to 0.21)	EE
Sour service	Moderately to highly corrosive	>30 (0.21)	FF
Sour service	Very corrosive	>30 (0.21)	HH

- All pressure-containing components should be treated as “bodies” for determining material requirements.
- Other boundary penetration equipment, such as grease/bleeder fittings and lockdown screws, should be treated as “stems.” Metal seals should be treated as pressure-controlling parts.

Table 22-4 Material Requirements [6]

Material Class	Minimum Material Requirements: Body, Onnet, End, and Outlet Connections	Minimum Material Requirements: Pressure-Controlling Parts, Stems, and Mandrel Hangers
AA — General service	Carbon or low-alloy steel	Carbon or low-alloy steel
BB — General service	Carbon or low-alloy steel	Stainless steel
CC — General service	Stainless steel	Stainless steel
DD — Sour service[a]	Carbon or low-alloy steel[a]	Carbon or low-alloy steel[b]
EE — Sour service[a]	Carbon or low-alloy steel[a]	Stainless steel[b]
FF — Sour service[a]	Stainless steel[a]	Stainless steel[b]
HH — Sour service[a]	CRAs[b]	CRAs[b]

[a]As defined by NACE MR 0175 [7].
[b]In compliance with NACE MR 0175 [7].

Main components of tree

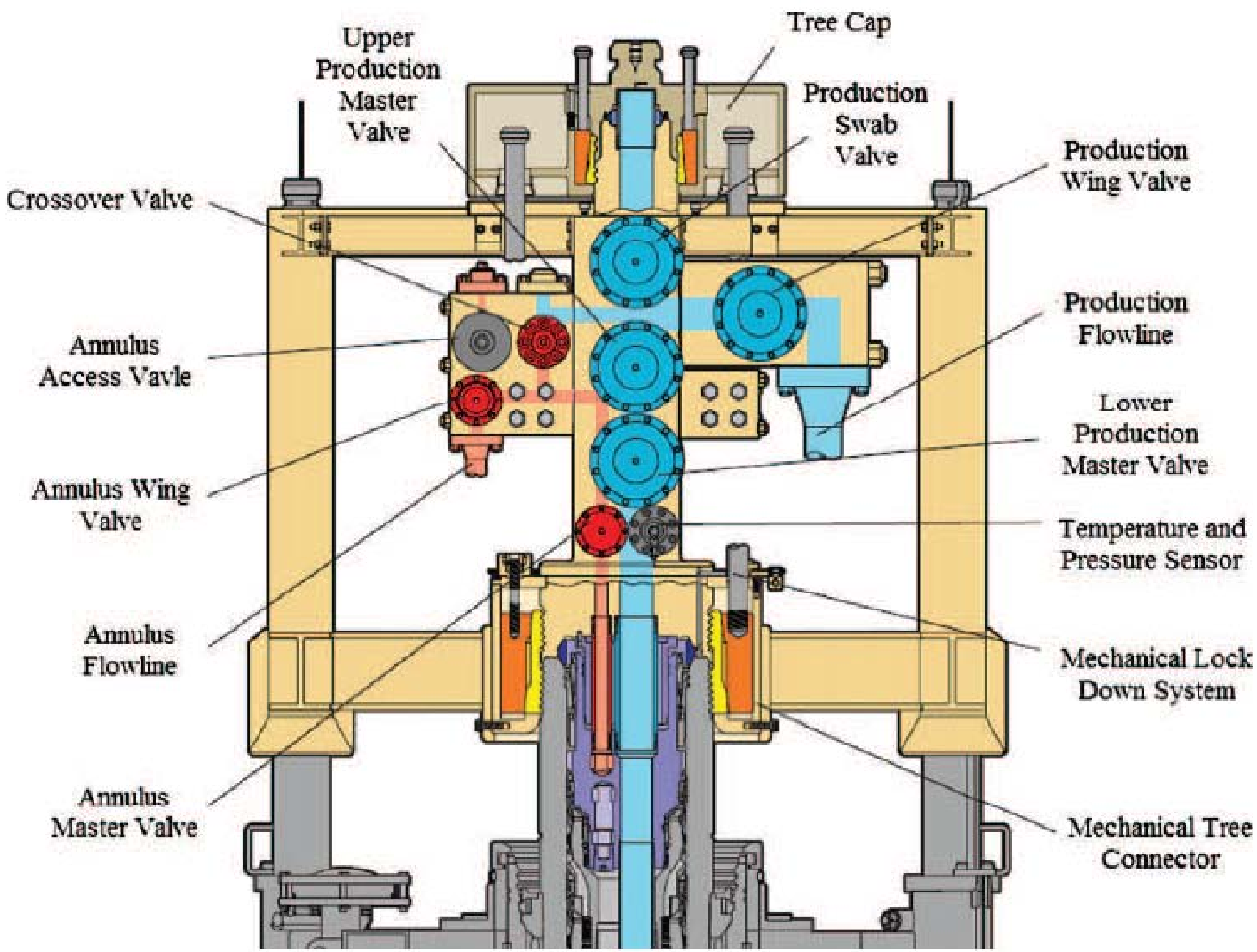


Figure 22-21 Typical Components of a VXT *(Courtesy of Dril-Quip)*

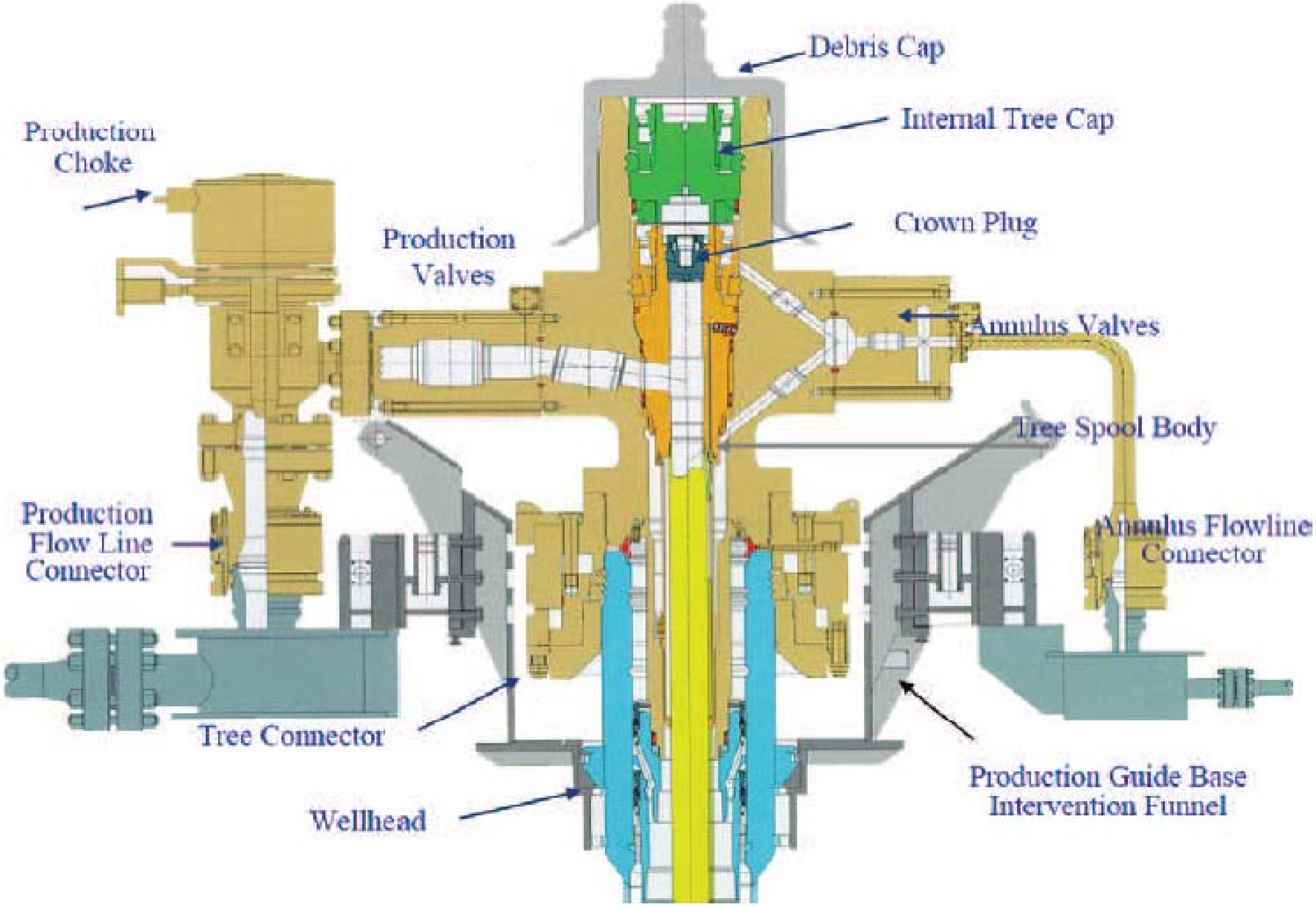


Figure 22-22 Typical Components of an HXT

VXT vs HXT

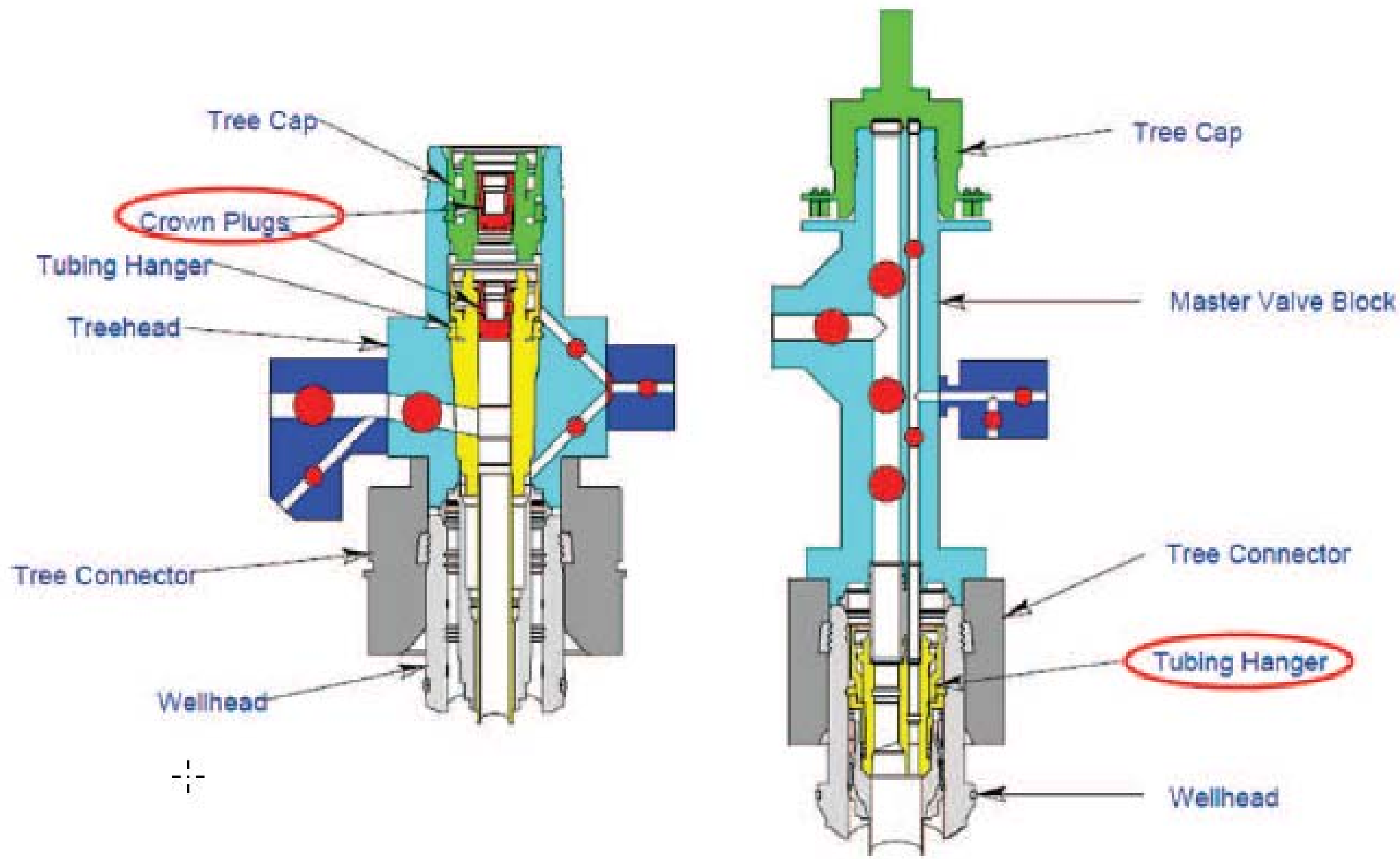


Figure 22-23 Differences between VXTs and HXTs *(Courtesy of Vetco Gray)*

- *Tree body:*

: The tree body in a HXT is normally designed to be an integrated spool.

: The PMV is located in the tree body, as well as the annulus valves.

: The PWV is usually designed to be integrated into a production wing block, which can be easily connected to the tree body by flange methods.

: This design results in components that are interchangeable between the HXTs in the industry.

- *Tubing hanger system*

: A VXT utilizes a conventional tubing hanger, which has a main production bore and an annulus bore.

: The tubing hanger is located in the wellhead. However, in an HXT, the tubing hanger is a monobore tubing hanger with a side outlet through which the production flow will pass into the PWV.

: Because the tubing hanger in the HXT is located in the tree body, it needs the crown plugs as the barrier method. An internal tree cap is the second barrier located above the crown plug. If dual crown plugs are designed in a tubing hanger system, an internal tree cap is not used.

- *Tree cap*

: The treecap in a VXT system has the functions of providing the control interfaces during workover and sealing the tree from seawater ingress.

: An HXT, in contrast, has internal tree caps and tree debris caps.

Tubing hanger

- In a subsea well, production tubing is supported and sealed off inside the subsea wellhead housing. The tubing hanger and the running tool necessary to install it comprise a tubing hanger system
- The basic functions of a tubing hanger are as follows:

: Suspend the tubing string(s) at the mudline level.

: Seal the annulus between the tubing and casing.

: Provide access to the annulus.

: Provide a through conduit(s) for SCSSV control, chemical injection, and monitoring.

: Provide an interface with the subsea tree.

Three factors characterize the basic tubing hanger system

- *Location*: wellhead/tubing hanger spool/tree body;
- *Size and designation*

: nominal wellhead size: 18 3/4, 16 3/4, or 13 5/8 in.

: production casing size: 10 3/4, 9 5/8 , 7 5/8, or 7 in.

: tubing string size: 2 3/8 , 3 1/2 , 4 1/2 , and 5 1/2 in.

- *Lockdown method*

: The mechanical set tubing hanger is run on a drill pipe tool and set by rotation.

: The hydraulic set tubing hanger, run on a completion riser, is set by a hydraulic tool driving a lock ring into a lockdown groove.

• Concentric bore or non-orienting tubing hanger;
• Multibore or orienting type of tubing hanger system.

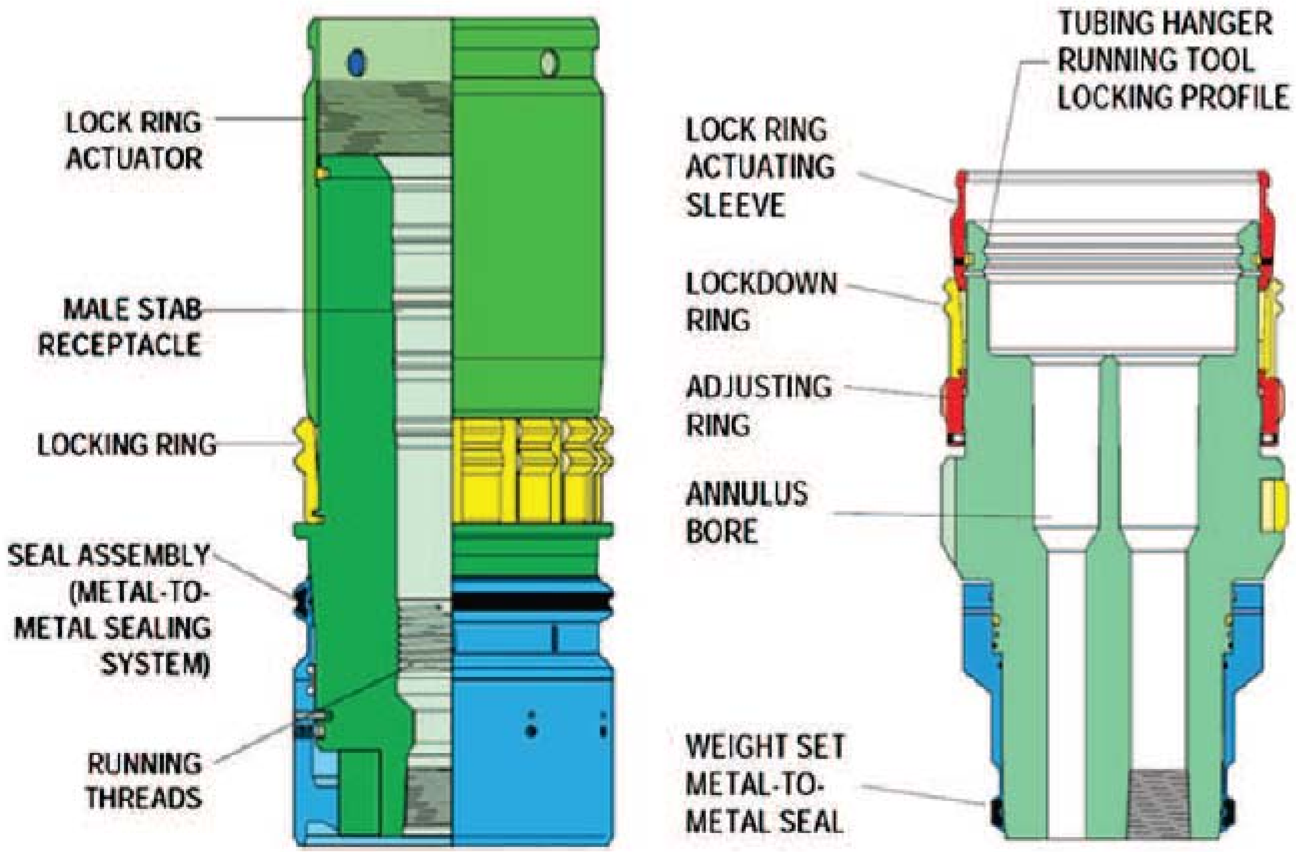


Figure 22-24 Concentric and Multibore Tubing Hangers *(Courtesy of Dril-Quip)*

- In a horizontal tree system, the tubing hanger configuration is normally of the concentric type, with a production outlet beside

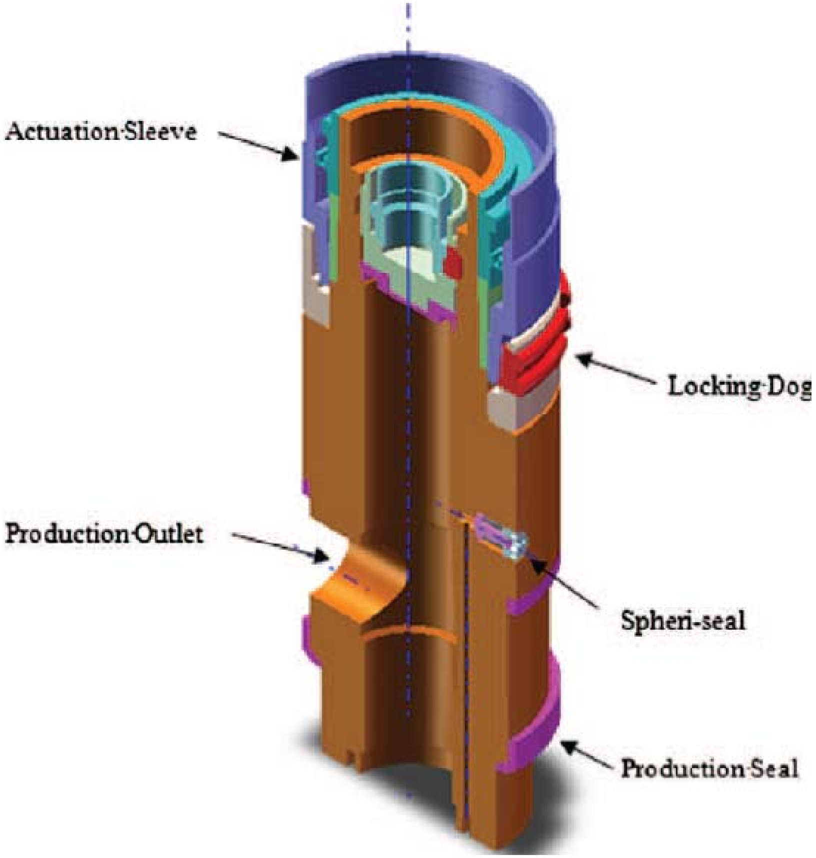


Figure 22-25 Horizontal Tubing Hanger Section View

Tree piping

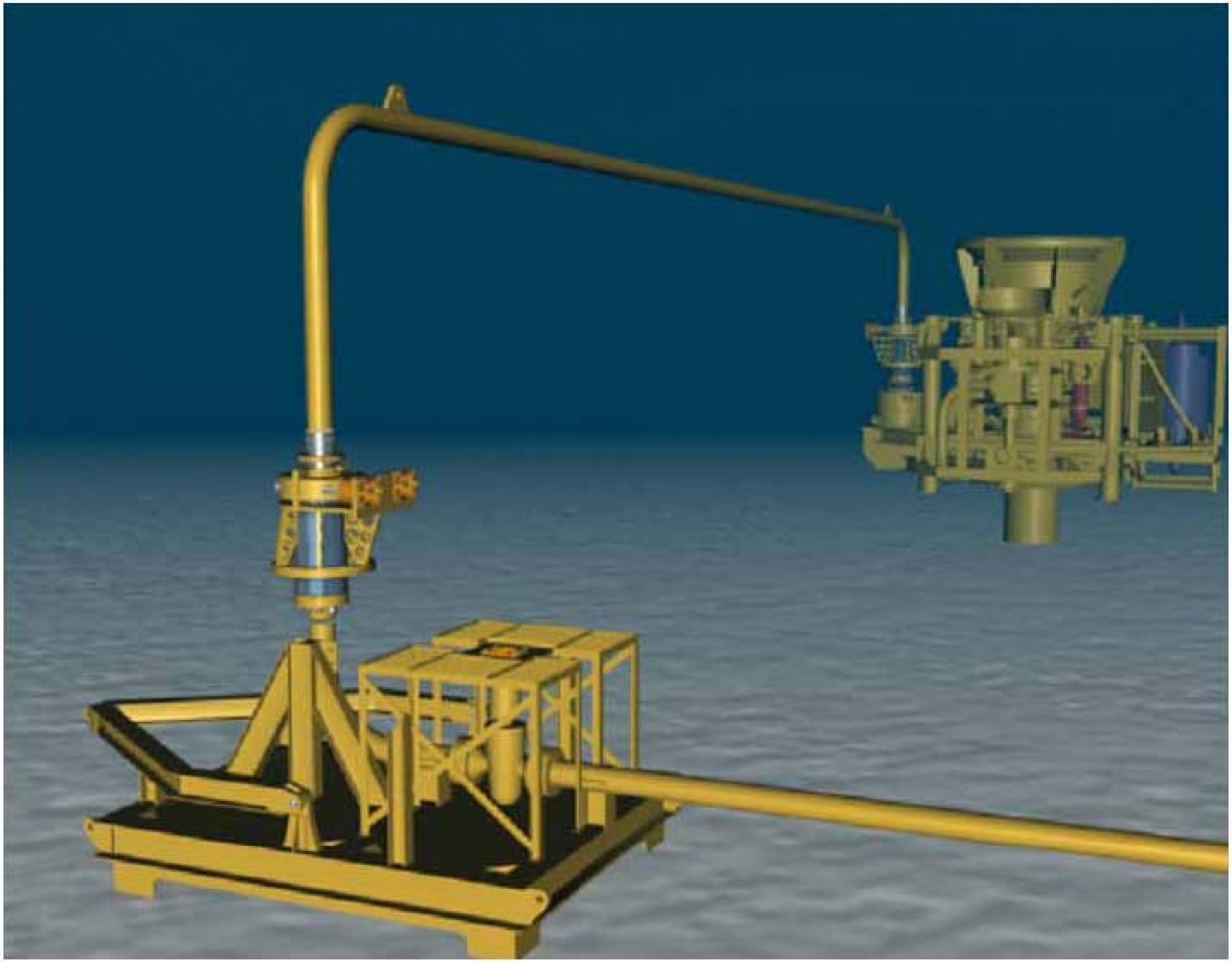
- Tree piping is defined as all pipe, fittings, or pressure conduits, excluding valves and chokes, from the vertical bores of the tree to the flowline connections.
- The piping may be used for production, pigging, monitoring, injection, servicing, or testing of the subsea tree.
- Inboard tree piping is upstream of the first tree wing valves.
- Outboard tree piping is downstream of the first tree wing valve and upstream of the flowline connector.
- Tree piping is normally designed in accordance with ASME B31.3

Flowline connector

- A flowline connector is used to connect subsea flowlines and umbilicals via a jumper to the subsea tree. In some cases, the flowline connector also provides the means for disconnecting and removing the tree without retrieving the subsea flowline or umbilical to the surface.

Figure 22-28 Flowline Connector *(Courtesy of FMC)*

Tie-in to flowline



- Flowline connectors generally come in three types

: manual connectors operated by divers or ROVs,

: hydraulic connectors with integral hydraulics,

: mechanical connectors with the hydraulic actuators contained in a separate running tool.

Tree connectors

- Tree connectors are used to land and lock the subsea Xmas tree to a subsea wellhead. They provide mechanical and pressure connections as well as orientation between the tree assembly and the wellhead.
- Mechanical tree connectors are generally diver actuated using a series of screws to energize a locking mechanism. Connectors of this type are suitable for type S (simple) and DA (diver assist) trees run from jack-ups and not recommended for trees run from floaters.
- Hydraulic tree connectors are the most common type of tree connector. They are suitable for all tree types.

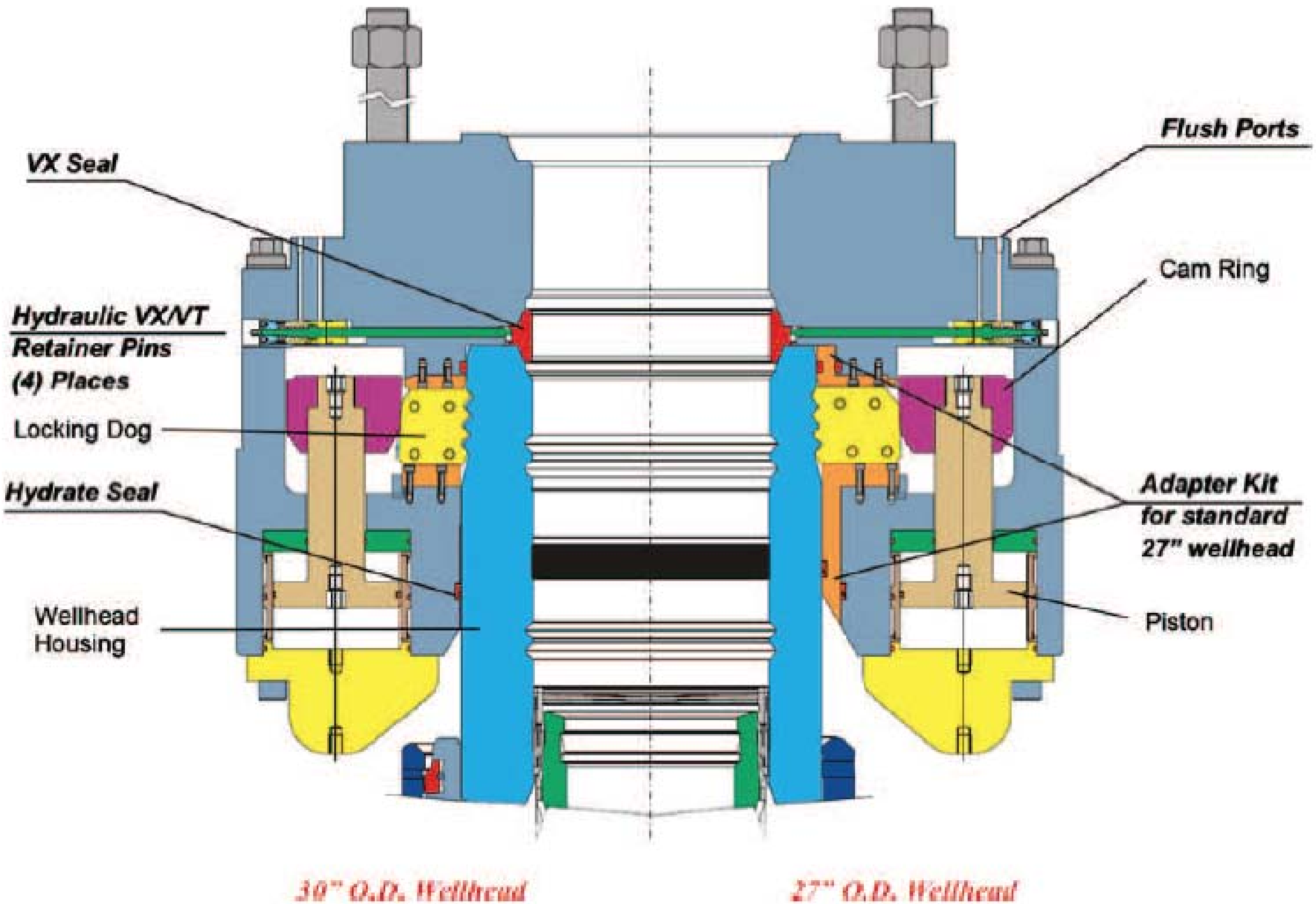


Figure 22-29 Hydraulic Tree Connector *(Courtesy of Vetco Gray)*

Tree valves

- Subsea Xmas tree contains various valves used for testing, servicing, regulating, or choking the stream of produced oil, gas, and liquids coming up from the well below

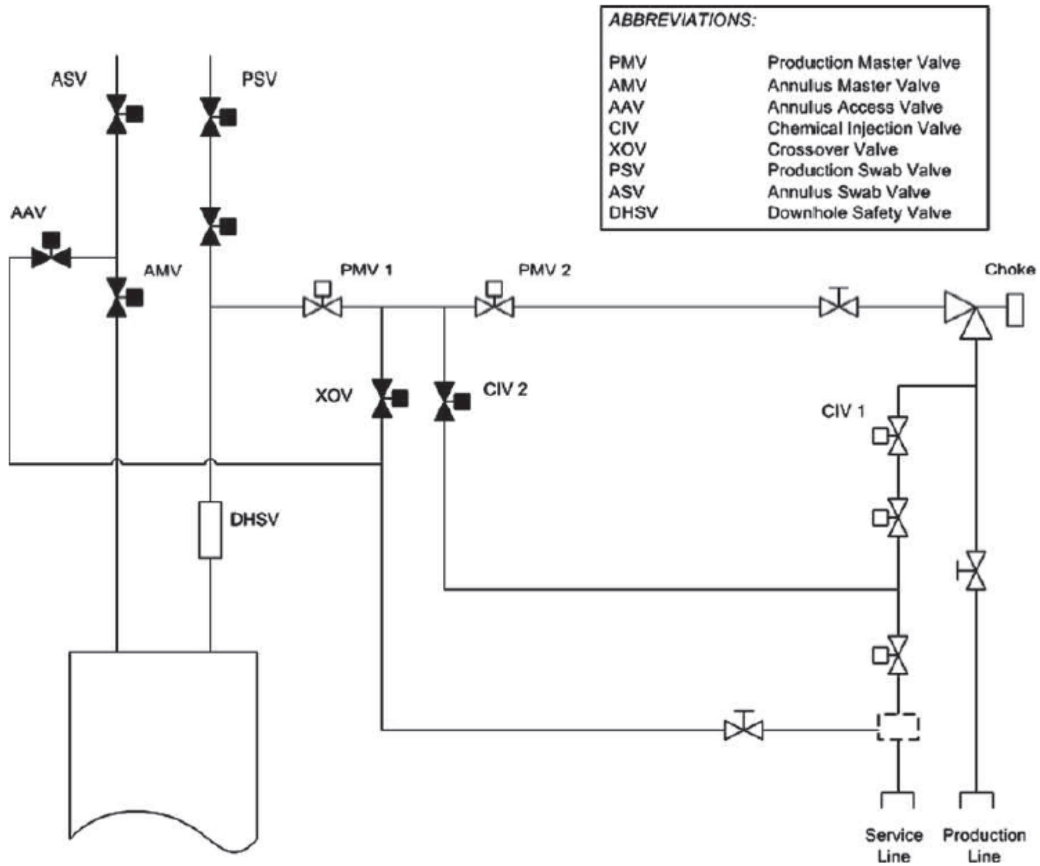


Figure 22-30 Configuration of Tree Valves

- The production flow coming from the well below passes through the downhole safety valve (DHSV), which will shut down if it detects an accident, leak, or overpressure occurring.
- Production master valves (PMVs) provide full opening during normal production. They must be capable of holding the full pressure of the well safely for all anticipated purposes, because they represents the second pressure barrier (the first is the DHSV). A production choke is used to control the flow rate and reduce the flow pressure.
- The annulus master valve (AMV) and annulus access valve (AAV) are used to equalize the pressure between the upper space and lower space of the tubing hanger during the normal production (i.e., when the DHSV is open).

- Located in the crossover loop, a crossover valve (XOV) is an optional valve that, when opened, allows communication between the annulus and production tree paths, which are normally isolated. An XOV can be used to allow fluid passage for well kill operations or to overcome obstructions caused by hydrate formation.
- The production swab valve (PSV) and annulus swab valve (ASV) are open when interventions in the well are necessary.

Production choke

- A production choke is a flow control device that causes pressure drop or reduces the flow rate through an orifice. It is usually mounted downstream of the PWV in a subsea tree in order to regulate the flow from the well to the manifold.

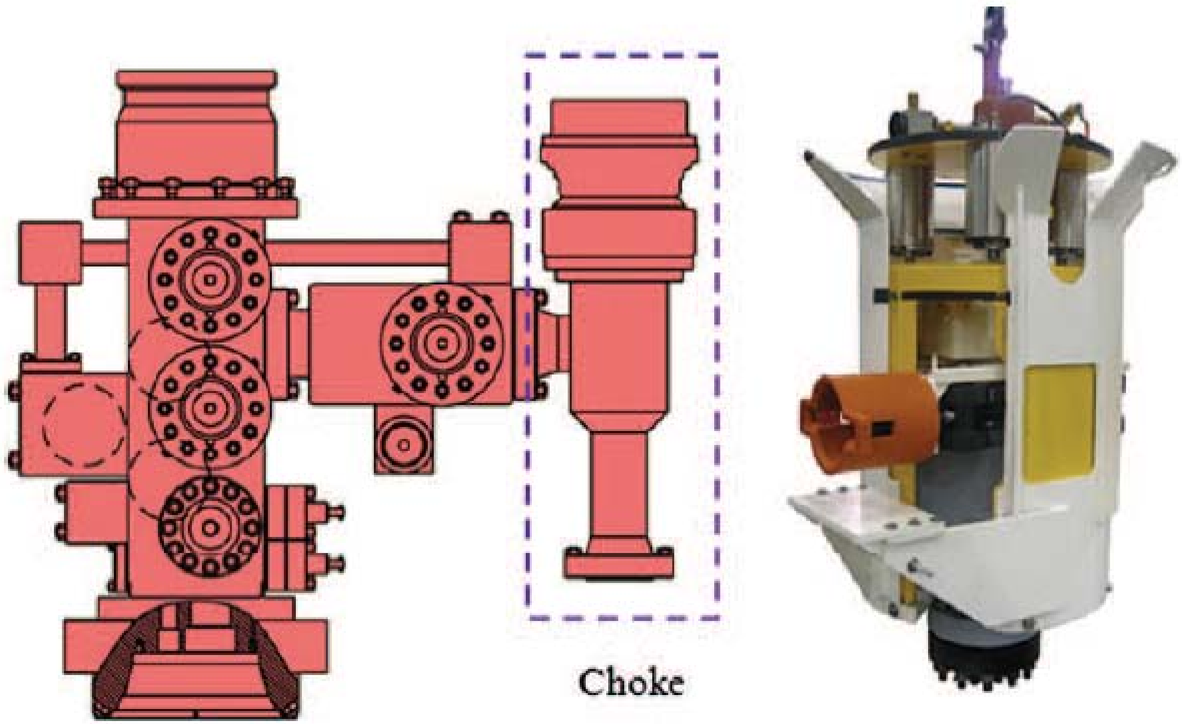


Figure 22-31 Subsea Choke *(Courtesy of Cameron and MasterFlo)*

- The two most widely used choke types are positive chokes and adjustable chokes.
- The adjustable choke can be locally adjusted by a diver or adjusted remotely from a surface control console.
- They normally have a rotary stepping hydraulic actuator, mounted on the choke body. This adjusts the size of orifice at the preferred value. Chokes have also been developed to be installed and retrieved by ROV tools without using a diver.

- Trims / orifices types

: Typical orifices used are of the disk type or needle/plug type.

: The disk type acts by rotating one disk and having one fixed. This will ensure the necessary choking effect.

: The needle/plug type regulates the flow by moving the insert and thereby providing a gap with the body. The movement is axial.

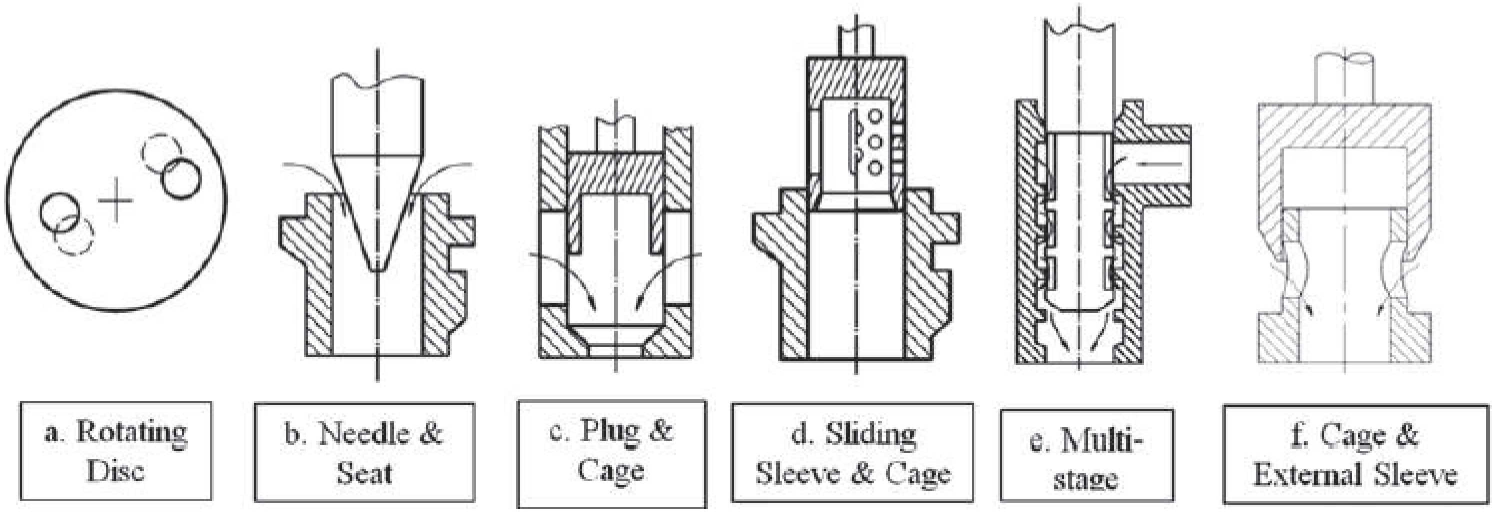


Figure 22-32 Trim Types

- Choke Design Parameters

: Several measurements must be known in order to select the proper choke for a subsea production system

: how fast the flow is coming into the choke, the inlet pressure *P1 of the flow, the pressure drop that occurs crossing the* orifice, and the outlet or downstream pressure *P2 of the flow,*

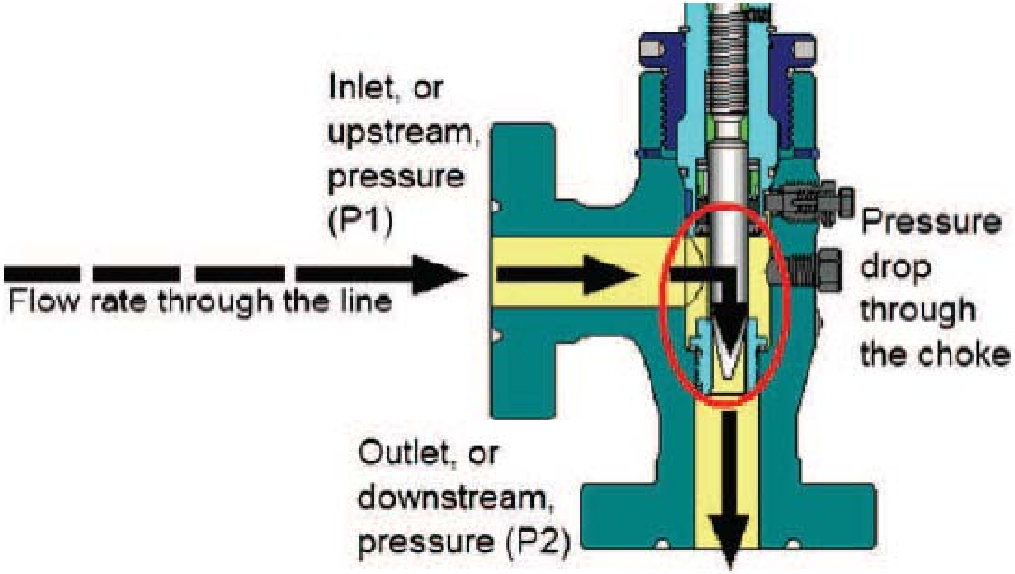


Figure 22-33 Choke Schematic *(Courtesy of Cameron)*

- Choke sizing is determined by coefficient value (Cv), which takes into account all dimensions as well as other factors, including size and direction changes, that affect fluid flow in a choke.
- The Cv equals number of gallons of per minute that will pass through a restriction (orifice) with a pressure drop of 1 psi at 60^{o}C.
- This Cv calculation normally follows Instrument Society of America (ISA) guidelines.

Pressure drop and recovery

- Pressure is maintained through the tree piping as P1. When the flow crosses the orifice of the choke, the pressure drops. But soon the pressure will recover to a level (P2).

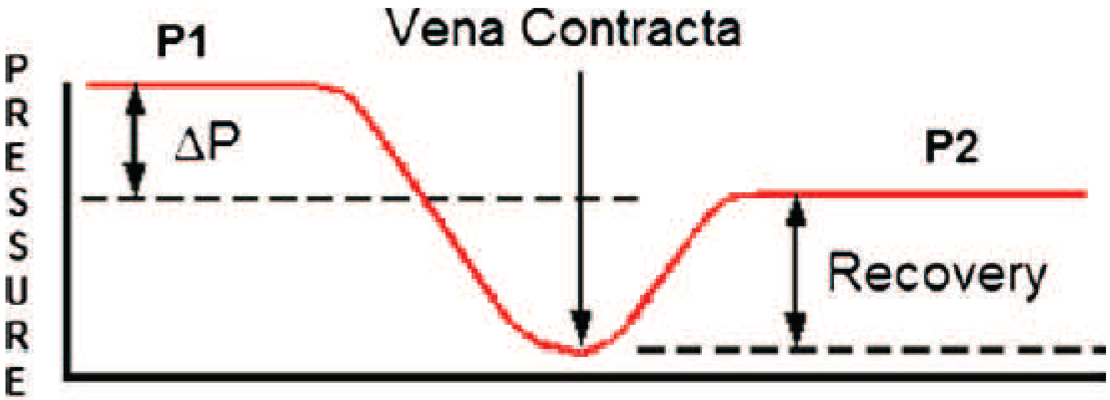


Figure 22-34 Pressure Drop in a Choke *(Courtesy of Cameron)*

- The pressure drop is determined by the equation *ΔP=P1 – P2 (inlet pressure minus outlet pressure)*.
- The *ΔP ratio, ΔPR = ΔP/P1.*
- It is considered the most important parameter for evaluating and ensuring the success of the subsea field development project.
- It is used to measure the capacity and recovery of the choke. The higher the value of *ΔPR*, the higher the potential damage to the choke trim or body. Normally a special review of the trim is required if DPR is beyond 0.6.

Tree cap

- Tree caps are designed to both prevent fluid from leaking from the wellbore into the environment and small dropped objects from getting into the mandrel.
- Tree caps are installed, locked, unlocked, released, and recovered via ROV-assisted operations.

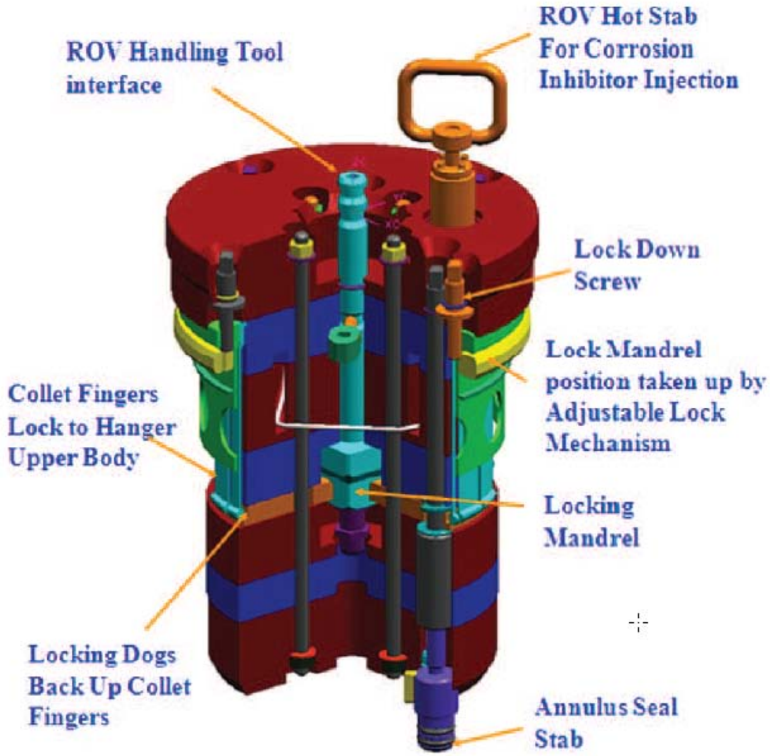


Figure 22-36 ROV-Operated Tree Cap *(Courtesy of FMC)*

Subsea control module

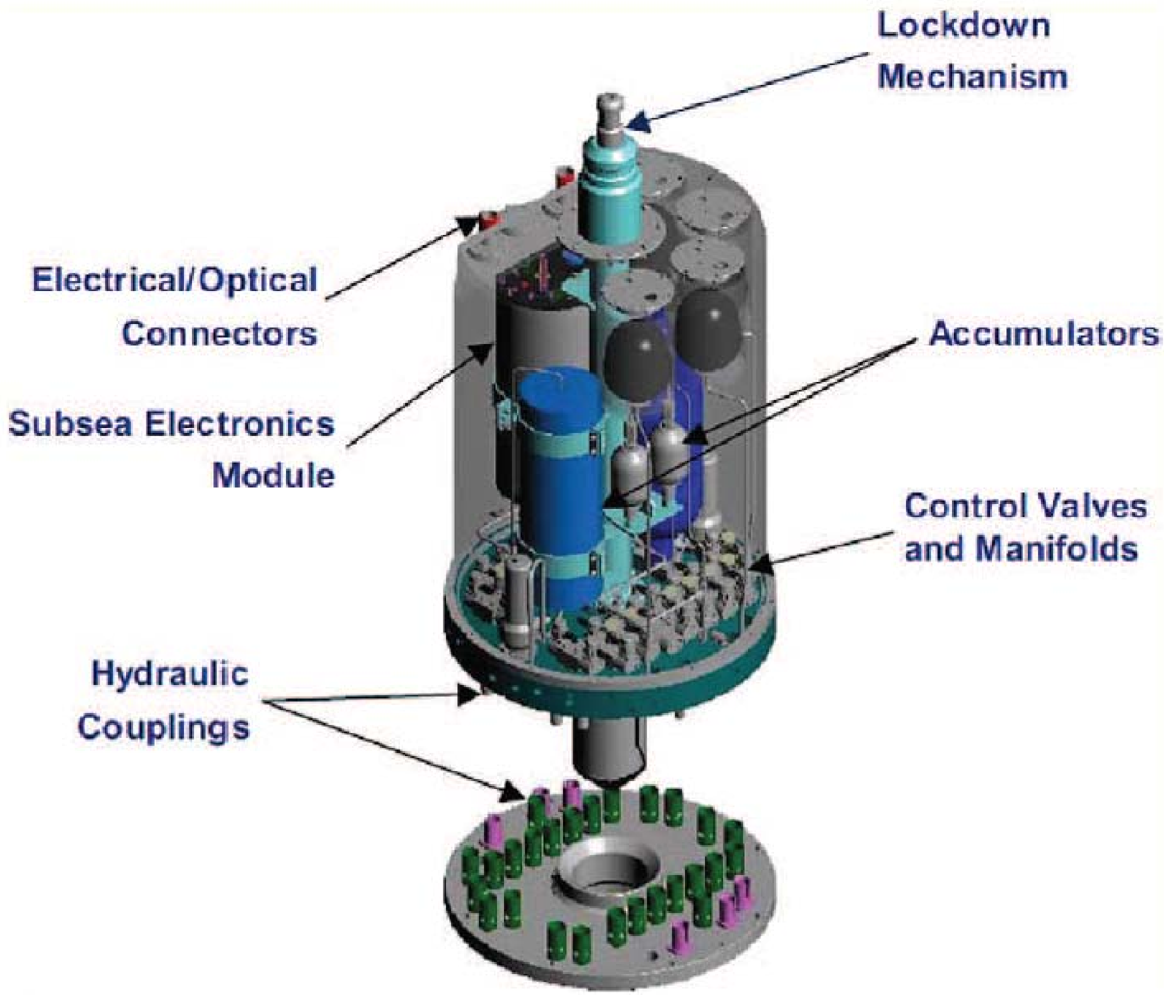


Figure 22-37 SCM Configuration

P and T transmitter

- pressure and temperature sensors are placed in the annulus and production bore and upstream and downstream of the choke.

Figure 22-38 PTT Located on a Subsea Xmas Tree

Chemical injection

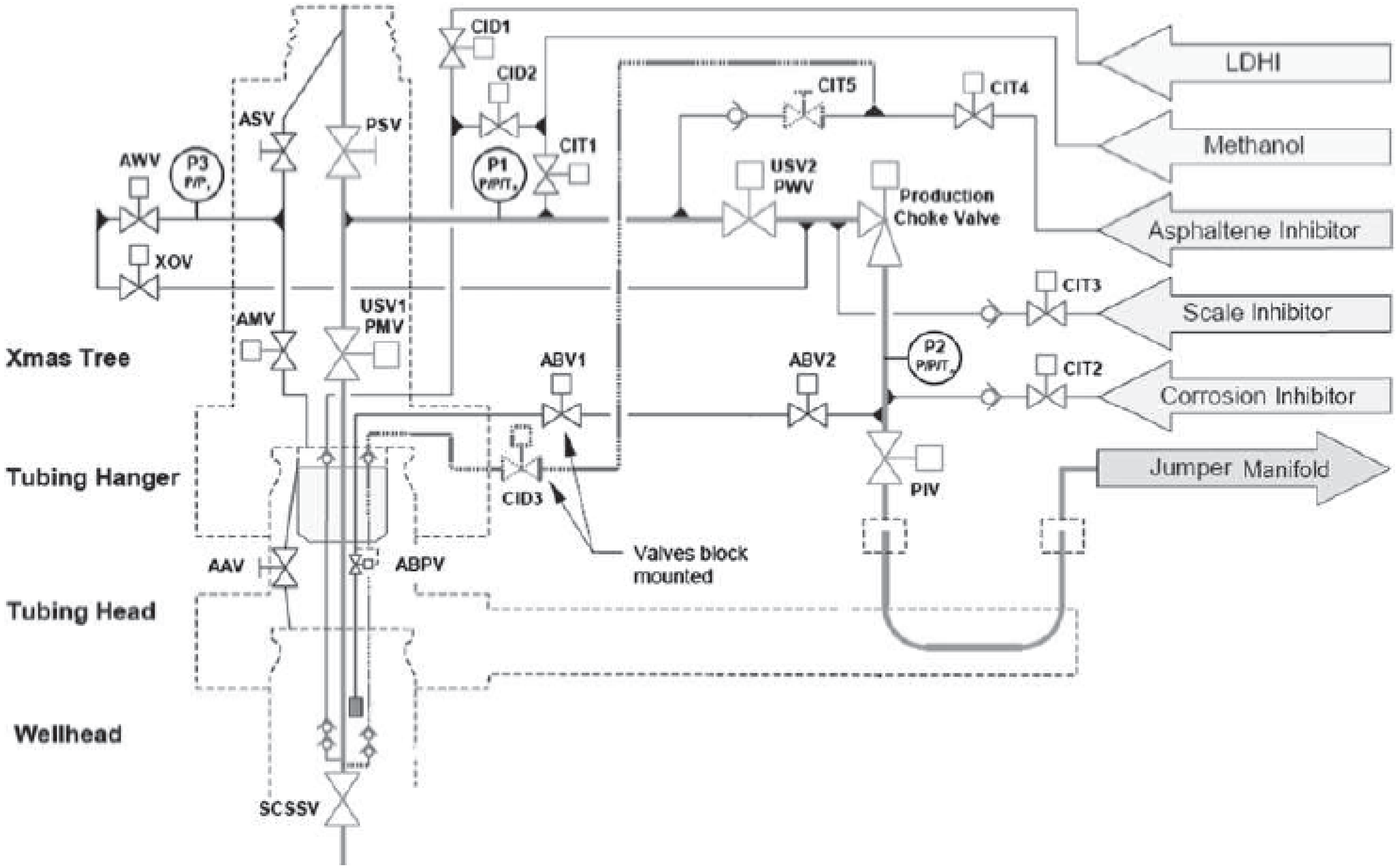
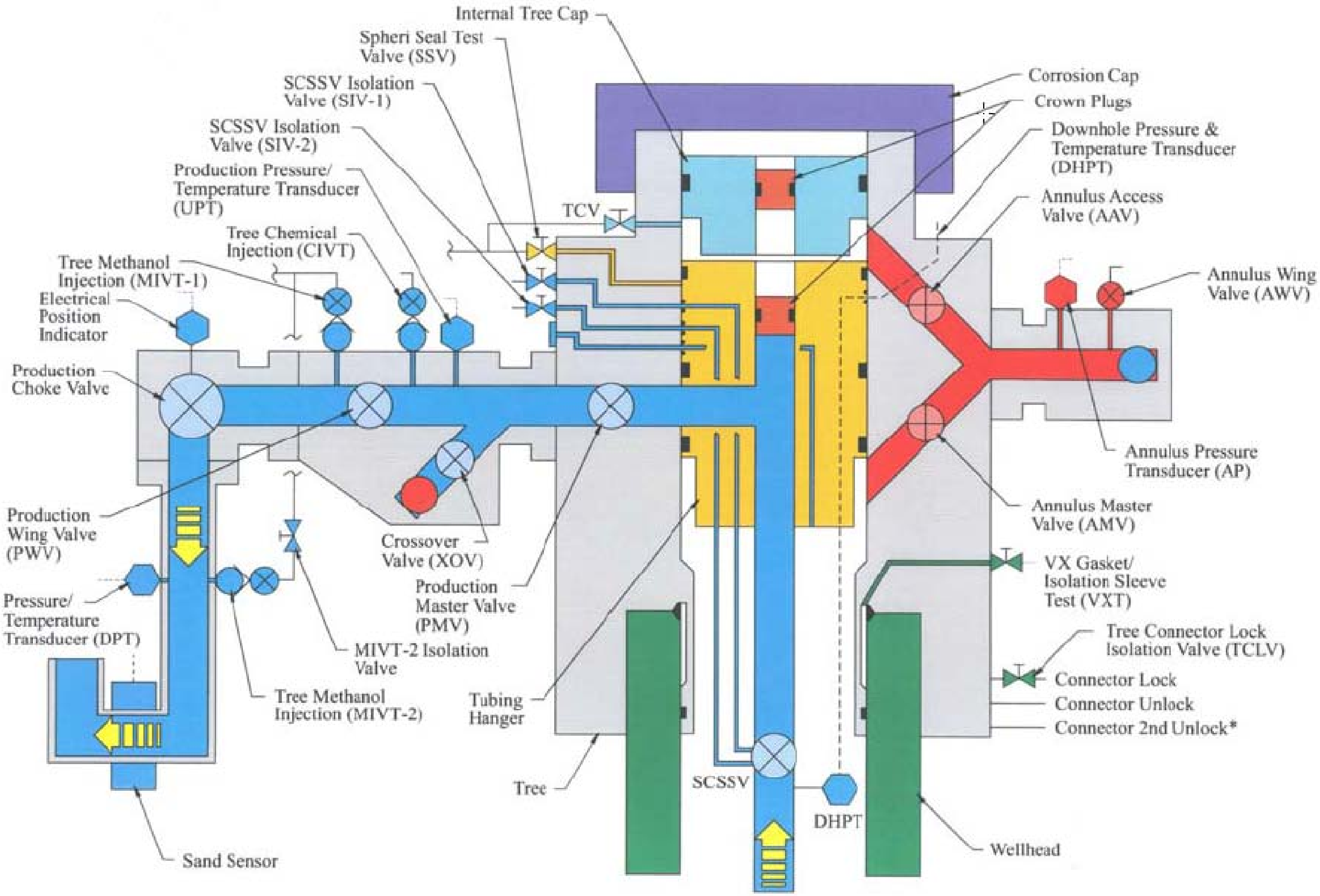


Figure 22-40 Example of Chemical Injection Design for Subsea Xmas Tree



Amerada Hess Conger Horizontal Tree P&ID

* Note: For DX Connector

Protection

- Cathodic protection is electrochemical protection that functions by making the metal surface of an electrochemical cell into a cathode that can decrease the corrosion potential to an acceptable level.
- The trees and wellhead require corrosion coatings and thermal insulation to enable sufficient cooldown time in the event of a production stoppage.

  : to have sufficient time to perform preservation sequence

  : to avoid dramatic consequences of hydrate formation

Installation

Figure 22-42 Tree Installation by Drill Pipe (Left) and Rig Winch (Right)

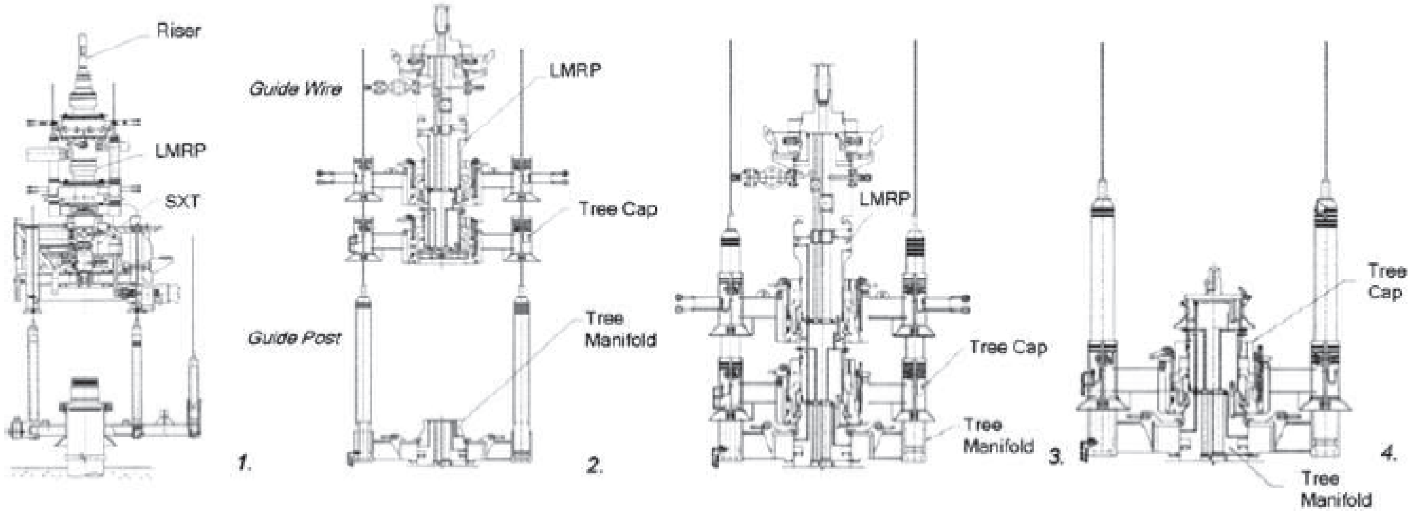


Figure 22-44 Vertical Xmas Tree Installation by Drill Pipe

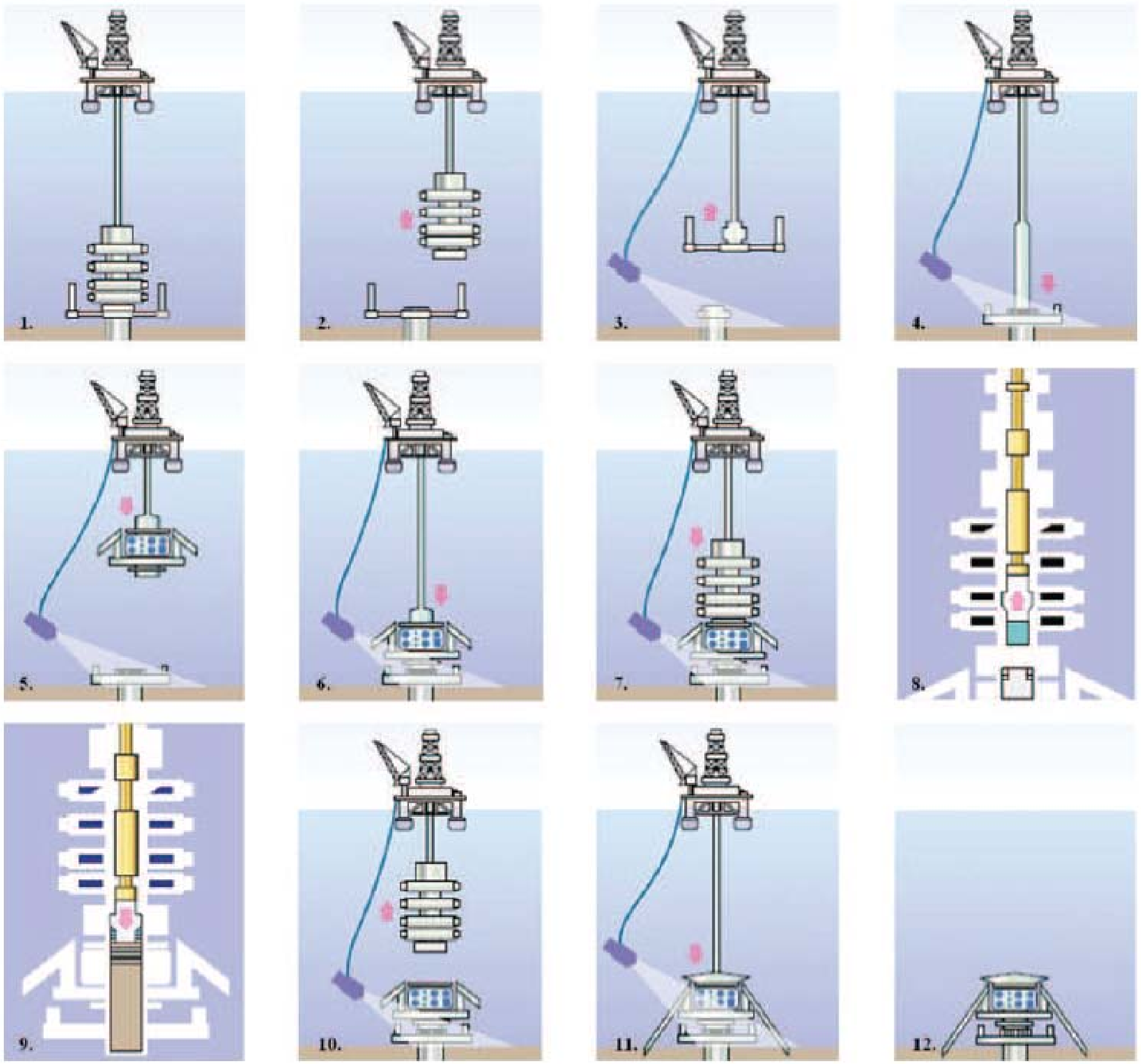


Figure 22-45 Horizontal Xmas Tree Installation Process *(Courtesy of Schlumberger)*

Next Class

: Manifolds