



TRAINING MANUAL

Process Engineering

GET - Process

Prepared by : Joby P P
Reviewed by : Barani G K
Approved by : Chellasamy S

Preamble

This training manual is intended to provide an introduction to the Graduate Engineering Trainees (GET) of process engineering discipline on their role and their interface with other disciplines; and to provide an overview of the activities to be performed by them under an engineering contracting organization.

This manual also acts as a guide and as a quick reference to various international standards to be used for their day-to-day process engineering activities.

This manual also gives an insight to other discipline GETs on the process engineering activities.

Contents

	Page
1. Introduction to Process Engineering	1
2. Process Engineering Projects	2
3. Role of Process Engineer	3
4. Interface with Other Discipline Engineers	4
5. Oil & Gas Projects.....	6
6. Phases of Project.....	7
7. FEED - Process Engineering Scope	10
8. EPC Proposals - Process Engineering Scope.....	11
9. Detailed Design - Process Engineering Scope	12
10. Basis of Design	13
11. Process Selection.....	14
12. Process Simulation	14
13. Flow Assurance Evaluation.....	17
14. Process Flow Diagram (PFD) and Heat & Mass Balance (H&MB)	18
15. Piping and Instrumentation Diagram (P&ID).....	19
16. Line Sizing.....	20
17. Pump Hydraulics Calculation	21
18. Vessel Sizing	23
19. Heat Exchanger Thermal Design	25
20. Relief Valve Sizing	27
21. Blowdown and Depressurization Study.....	29
22. Flare Design	30

1. Introduction to Process Engineering

Process engineering design is the application of chemical, petroleum, gas, integrated with mechanical, instrumentation and other engineering talents to the process-related development, planning, design and decisions required for economical and effective completion of a process project.

The process design engineer actually engineers the process chemistry into appropriate hardware (equipment) to accomplish the process requirements. His task is to find the best way to produce a given quality product, safely and economically.

Process engineer has the following responsibilities:

1. Studies process systems for manufacture of a product or to implement improvements / changes in existing production units.
2. Prepares economic studies associated with process performance.
3. Evaluates operating data of existing or new equipment.
4. Designs and/or specifies items of equipment required to define the process flowsheet or flow system.
5. Evaluates competitive bids for equipment.

The process engineer must understand the interrelationship between the various research, standards, engineering, purchasing, expediting, construction and operational functions of a project. He must appreciate that each function may and often does affect or influence the process design decisions.

In a consulting or engineering contractor organization, process design and/or process engineering is usually a separate group responsible for developing the process with the customer, or presenting the customer with a turnkey proposed process.

2. Process Engineering Projects

For any typical process related project, the process engineer begins by gathering all the data / information he can about the process and the physical & chemical information of the substances involved in the process.

The initial goal of the preliminary process study is to obtain an economic evaluation of the process, with the minimum expenditure of time and money. During this stage, all information necessary to obtain a reasonably accurate cost estimate for building and operating the plant is determined.

In the design and evaluation of a process, the process engineer takes the following activities. These are the selection of a site, the writing of the scope (definition of project), the choosing of the process steps, the calculation of material and energy balances, the listing of all major equipment with its specifications, the development of the physical layout of the plant, the instrumentation of the plant, the development of a cost estimate; and finally the economic evaluation of the process.

If the techno-economic evaluation appears promising, then this process must be compared with all other alternatives to determine whether taking the proposed action is really the best course to follow. All these feasibilities must be economically evaluated to determine the best course of action to take.

If, after comparing alternatives, a project is approved by the management, the project is returned to process engineering for the detailed process design. Now the process engineer must provide all the information necessary to the project engineering specialists, so that equipment can be designed and specified.

3. Role of Process Engineer

Process engineer must be conversant to carry out the following activities.

- Prepare heat and material balance studies for a proposed process, with and without use of software applications.
 - Prepare rough cost economics, including preliminary sizing and important details of equipment, factor to an order of magnitude capital cost estimate, prepare a production cost estimate, and work with economic evaluation representatives to establish a payout and the financial economics of the proposed process.
 - Participate in layout planning for the proposed plant.
 - Prepare operating, control and safeguarding philosophies of the plant.
 - Prepare and supervise drafting of process flow diagrams (PFD).
 - Prepare and supervise drafting of piping and instrumentation diagram (P&ID), with necessary preliminary sizing of all piping, equipment and representation of all instrumentation for plant monitoring, automation and protection.
 - Prepare detailed sizing of all process equipment and utility systems, with and without use of software applications.
 - Prepare process datasheet for all equipment and package systems. This is used by mechanical engineers to prepare a detailed equipment specification.
 - Determine size and specifications for all safety relief valves.
 - Select piping specifications from existing company standards for the fluids and their operating conditions for incorporation in P&ID.
 - Select from company insulation standards the insulation codes to be applied to each hot or cold pipe or equipment as applicable.
 - Prepare line schedule, equipment summary schedules, summary schedules for safety relief valves and rupture disks.
 - Perform technical evaluation of bids and recommendation of qualified vendors.
-

4. Interface with Other Discipline Engineers

Once the project begins to take shape with initial inputs from process engineers, the design work by other engineering disciplines begin with evaluating the process engineering documents and drawings. Additional design information and details are provided by them to bring the project to a complete shape. The role of each engineering discipline in the project design cycle is detailed below.

Mechanical Engineering:

- Preparation of equipment (static, rotating, packages) specification or mechanical datasheets based on process datasheets. The Mechanical data such as design data, protective coating & insulation, scope of supply, material of construction, nozzles data, equipment sketch, shall be included complying the requirements of client technical specifications and applicable international codes and standards.
- Evaluation of equipment heat dissipation for estimation of heat load for HVAC system and selection of HVAC equipment.

Piping / Pipeline Engineering:

- Identifies site area & boundary limits and prepare plant layout.
- Identifies pipeline destination and route options.
- Prepares plot plan, equipment layout and performs accessibility study.
- Prepares piping layout & study options.
- Prepares piping material specification.
- Prepares tie-in schedule.
- Prepares piping material take-off (MTO).

Electrical Engineering:

- Identifies and evaluates the electrical & power availability, generation, distribution and consumption for the plant.
- Performs electrical system studies including short circuit study, load flow study & equipment sizing, motor starting study.
- Prepares electrical load balance.
- Prepares electrical design basis.
- Performs HV/MV cable sizing.
- Prepares key single line diagrams.
- Prepares electrical cable schedule.
- Prepares overall cable routing layouts.
- Prepares electrical bill of quantities (BOQ).
- Prepares main substation layouts.
- Prepares electrical equipment specifications and data sheets.

Civil & Structural Engineering:

- Evaluates soil data or seabed conditions for site grading & foundation requirements, together with survey, seismic data & met-ocean data for offshore structures.
- Prepares structural philosophy.
- Performs structural analysis & design.
- Prepares constructability / erectibility & operability philosophy.
- Prepares transportation philosophy, wherever applicable.
- Prepares civil & structural material take-off (MTO).

Instrumentation Engineering:

- Prepares control system & instrument philosophy.
- Identifies type of control systems required.

- Prepares metering philosophy.
- Prepares control system specification (DCS/ESD/FGS etc).
- Prepares control system topology diagram.
- Prepares control system block diagram.
- Conducts SIL review.
- Prepares control valve specification and performs control valve sizing.
- Prepares field instrument data sheets & specifications.
- Prepares instrument schedule.
- Prepares I/O list (DCS/ESD/F&G etc).
- Prepares instrumentation material take-off (MTO).

Telecom Engineering

- Prepares telecom system Basis of Design
- Prepares telecommunication philosophy
- Prepares telecom system specifications.
- Prepares telecom block diagrams.
- Prepares telecom routing & layout diagrams.
- Prepares telecom cable schedule.
- Prepares telecom equipment schedule.
- Prepares telecom material take-off (MTO).

HSE Engineering:

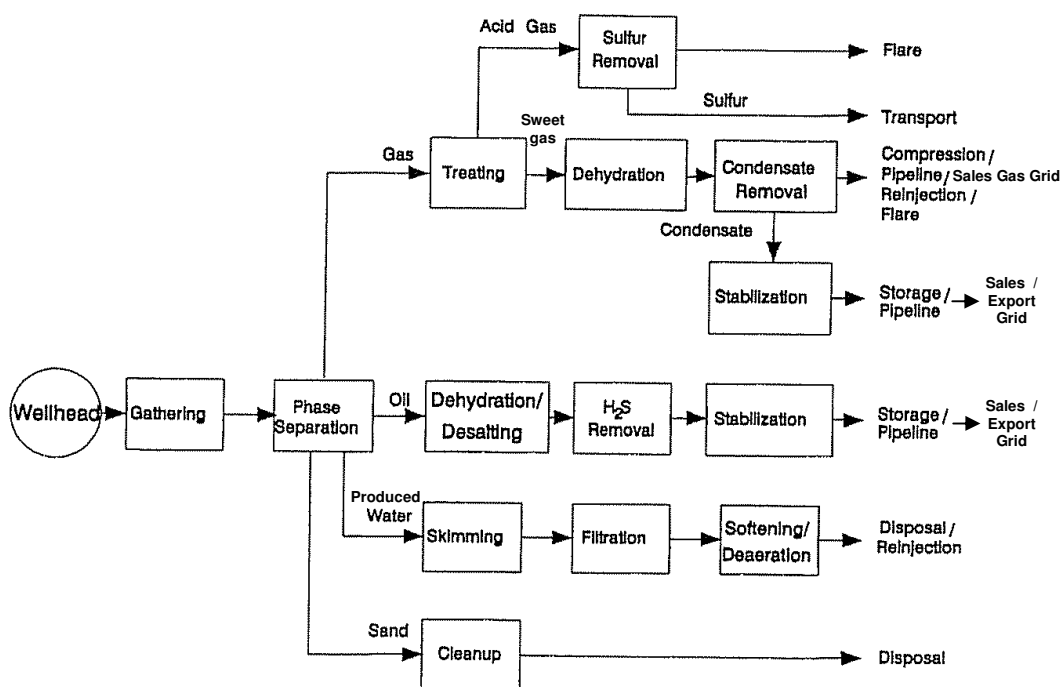
- Identifies gaseous emissions & produced water disposal quantities.
 - Prepares HSE Design Philosophy, Safety concept, Fire protection Philosophy.
 - Prepares Safety and Fire fighting equipment layout.
 - Prepares Emergency Escape route layout.
 - Prepares Hazardous area classification schedule / layout.
 - Identifies Fire and Gas detection system and Fire Suppression system.
 - Conducts HSE Review (HAZID, HAZOP) of the project.
 - Carries out risk assessment studies (QRA, SIMOPS, FERA etc).
 - Performs Availability / Reliability Analysis.
 - Carries out Environmental Studies (EIA, ENVID etc).
 - Prepares HSE material take-off (MTO).
-

5. Oil & Gas Projects

The Oil & Gas processing starts at wellhead and proceeds with gathering at manifolds, transferring through trunk lines, and further processing by separation, stabilization, storage and pumping into sales grid. Oil & Gas processing consists of two distinct categories of operation:

- Separation of gas-oil-brine well stream into its individual phases.
- Removal of impurities from the separated phases to meet sales / transportation / re-injection specifications and/or environmental regulations.

The following figure gives a simplified overview of the typical oil & gas production process.



All the various modules shown above will not be present in every system. Furthermore, the modules used in a given application may not be arranged in the same sequence as shown above. The selection and sequencing of modules is determined during the design phase of field development.

After the above field process, the crude cannot be used directly, and must be processed in refineries to produce fractions that are themselves useful, or that becomes useful when chemically processed and/or properly blended. But refinery is another major industry.

6. Phases of Project

A process engineering project passes through the following engineering phases and the activities taken up in each phase of the project are detailed subsequently.

- Feasibility Study
- Concept Engineering
- Front End Engineering Design (FEED)
- Proposal Engineering for EPC Bid
- Detailed Engineering

Once a substantial detailed engineering is done, the project proceeds through the procurement, construction and commissioning phase for completion. The plant is then operated to test the intended performance and the operating parameters are optimized for a stable and sustained operation.

Feasibility Study

- Establish elements & building blocks of agreed concepts.
- Review technical feasibility, cost and schedule for concepts and blocks.
- Compare, evaluate and rank the concepts with a set of agreed criteria.
- Identify preferred options for study.
- Prepare preliminary engineering deliverables for each option.
- Generate cost estimate ($\pm 40\%$ accurate) and schedule for each option.
- Select the feasible concept and issue Feasibility Study Report.

Concept Engineering

- Review Feasibility Report
- Review applicable codes, standards & legislation.
- Develop preliminary Process Design (H&MB, PFD, Equipment List)
- Develop preliminary Equipment datasheets and Plot Plan.
- Develop preliminary Engineering Philosophies (HSE, Electrical, C&I, Civil)
- Perform HAZID and risk analysis
- Generate cost estimate ($\pm 30\%$ accurate).
- Develop preliminary Project Development, Execution and Procurement Plans.
- Prepare and Issue Concept Design Report and Basis of Design.

Front End Engineering Design (FEED)

- Review Concept Design Report and Basis of Design.
- Review applicable codes, standards & legislation.
- Develop firm Process Design (H&MB, PFD, Equipment List)
- Detailed Flow Assurance Evaluation
- Perform Process Studies and selection of technologies.
- Develop Process Philosophies
- Major Equipment sizing, selection and datasheets.
- Develop P&ID and perform sizing of major piping.
- Develop Material Selection Report
- Develop Plot Plan
- Perform HAZOP review & issue HAZOP report
- Develop Mechanical datasheets and specifications for major equipment.

- Develop engineering design for Pipeline, Piping, Civil, Electrical, HSE, C&I, Telecom etc.
- Produce MTOs (Piping, Structural, Civil, Electrical, Instrument etc.)
- Issue Request for Budget quotations for major equipment.
- Generate Requisitions & issue RFQs for long lead items.
- Perform Technical & Commercial Bid Evaluations of vendor quotes and provide recommendations.
- Develop Procurement Plan, Preferred Suppliers list, Logistics study.
- Generate Cost Estimate ($\pm 20\%$ accurate)
- Define Project Execution Plan.
- Update Basis of Design
- Generate Invitation to Tender for Engineering, Procurement & Construction (EPC) Contract.

Proposal Engineering for EPC Bid

- Review of FEED documents supplied along with Tender.
- Check consistency among documents, design basis, compliance with project specification, codes and standards.
- All engineering documents and drawings related to Process, HSE, Mechanical, Pipeline, Piping, Civil, Structural, Electrical, C&I, Telecom etc. are studied critically for consistency with the scope of work and adequacy for meeting the design intent by respective discipline.
- Review process requirements / guarantees / warranties.
- Review safety aspects of the design.
- Prepare MTO and BOQ.
- Issue Request for Budget quotations for major equipment.
- Generate Requisitions & issue RFQs for long lead items.
- Perform Technical & Commercial Bid Evaluations of vendor quotes and provide recommendations.
- Develop Procurement Plan, Logistics study.
- Develop Project Execution Plan and schedule.
- Prepare manhour estimate.
- Prepare FEED verification report and /or Technical Proposal.
- Identify risk items in the proposal.
- Generate Cost Estimate and prepare Commercial Proposal to bid for the EPC contract.

Detailed Engineering after award of EPC contract

- Review scope of work.
- Development of organization chart.
- Finalize Technical Document Register (TDR).
- Review FEED documents and update Design Basis.
- Review applicable codes, standards & legislation.
- Validate and update Process Design (H&MB, PFD, Equipment List).
- Validate and update Flow Assurance Evaluation.
- Perform Process Studies.
- Update Process Philosophies (Operating & Control, Isolation, Shutdown, Blowdown, Flaring, Draining, Sparring, Insulation & Winterization etc.).
- Validate Equipment sizing, prepare Equipment list and Process Datasheets.
- Detail out and update P&ID, validate sizing of piping and prepare line list.
- Validate and update Material Selection Report.
- Validate and update Plot Plan.
- Perform HAZOP review, issue HAZOP report and close-out HAZOP actions.

- Develop Mechanical datasheets and specifications for all equipment.
 - Detail out engineering design for Pipeline, Piping, Civil, Electrical, HSE, Instrumentation, Telecom etc.
 - Produce MTOs (Piping, Structural, Civil, Electrical, Instrument etc.)
 - Generate Requisitions & issue RFQs for all equipment and items.
 - Perform Technical & Commercial Bid Evaluations to shortlist vendor quotes for procurement and order placement.
 - Review of post-order vendor documents for design consistency.
 - Issue Engineering Design Manual.
 - Prepare and issue Pre-Commissioning and Commissioning Procedures.
 - Prepare and issue Operating & Maintenance Manuals.
-

7. FEED - Process Engineering Scope

Inputs

- Basis of Design
- Concept Engineering Report
- Preliminary Process Design (H&MB, PFD, Equipment List)
- Preliminary Equipment Datasheets and Plot Plan
- Preliminary Engineering Philosophies (HSE, Electrical, C&I, Civil)

Process Activities

- Process Selection
- Process Simulation
- Flow Assurance Evaluation
- Develop Process Philosophies (Operating & Control, Isolation, Shutdown, Blowdown, Sparing, Insulation & Winterization etc.)
- Selection & Sizing of major Equipment
- Sizing of major piping
- Evaluation of relief scenarios and relief valve sizing
- Process Studies (Optimization, Energy conservation, Flare & Blowdown study etc.)
- Inter-department Inputs (Material Selection, Plot plans, HAZID, HAZOP & SIL studies etc.)

Process Deliverables

- Updated Basis of Design
 - Process Design Philosophies
 - Process Study Reports
 - H&MB
 - PFD, UFD
 - P&ID
 - Equipment List
 - Process Datasheets (Equipment, Instrument)
 - Cause & Effect Diagram
 - Utility Summary
 - Line List
-

8. EPC Proposals - Process Engineering Scope

Inputs

- FEED Deliverables

Process Activities

- Verification and validation of FEED Documents
- Vendor document review

Process Deliverables

- Validated FEED Documents
 - Process Write-up for Technical Proposal
-

9. Detailed Design - Process Engineering Scope

The main difference between FEED and Detailed Design is that, the FEED starts with minimum information and proceeds through client interaction for agreement on finalizing the design. Detailed Design starts with substantial information which is in agreement with client. However, selection of vendor for various equipment, packages and instruments is finalized only during detailed design of EPC phase and this information is integrated into the design of the connected system to satisfy the design intent of the whole project.

Inputs

- FEED Documents (refer Section-7)

Process Activities

- Process Simulation
- Flow Assurance Evaluation
- Update Process Philosophies (Operating & Control, Isolation, Shutdown, Blowdown, Sparing, Insulation & Winterization etc.)
- Sizing of Equipment and piping
- Evaluation of relief scenarios and relief valve sizing
- Process Studies (Optimization, Energy conservation, Flare & Blowdown study etc.)
- Inter-department Inputs (Material Selection, Plot plans, HAZID, HAZOP & SIL studies etc.)
- Vendor Document review

Process Deliverables

- Updated Basis of Design
 - Updated Process Design Philosophies
 - Process Study Reports
 - H&MB
 - PFD, UFD
 - P&ID
 - Equipment List
 - Process Datasheets (Equipment, Instrument)
 - Cause & Effect Diagram
 - Utility Summary
 - Line List
 - Input to Design Manual, Pre-Commissioning & Commissioning Procedures, Operating & Maintenance Manual.
-

Key Process Input:

10. Basis of Design

Basis of Design is the key input document to start the FEED and Detailed Design activity. The content of this document are as follows.

- Nature of the facility, location, ownership, potted history, when and where design is to be carried out.
 - Major design constraints (e.g., for political, commercial, technical or schedule reasons).
 - Inlet fluid conditions, flow rates, compositions, properties.
 - Required product specifications, delivery locations and conditions, throughputs, turndown and availability.
 - Specified proprietary or licensed processes or technologies.
 - Design Life and provisions for future modifications.
 - Sources and conditions of utilities.
 - Disposal methods for by-products and effluents.
 - Battery limits / interfaces with third parties.
 - Local infrastructure data.
 - Environmental conditions (seasonal, meteorology, ocean, topography, soils, seismic).
 - Significant aspects of Client philosophies (HSE, O & M, fabrication, construction and installation, start-up date, other Client limitations.)
-

Key Process Activities:

11. Process Selection

Process Selection begins at Concept Engineering phase and involves selection, sequencing and defining various unit processes and unit operations to achieve the concept engineering objectives.

It involves the selection and ordering of the processing steps and the setting of process conditions. This is a highly innovative activity and is the portion of plant design where, potentially, the largest savings can be realized. The proper placement of the various steps involved can result in smaller, less expensive equipment and fewer losses. The wise choice of operating conditions can eliminate the need for much expensive peripheral equipment.

12. Process Simulation

Process Simulation involves engineering the Heat & Mass balance of the selected process. Various process simulations packages are available commercially and are equipped with a large number of component database and built-in property packages to provide accurate thermodynamic, physical, and transport property predictions for hydrocarbon, non-hydrocarbon, petrochemical, and chemical fluids.

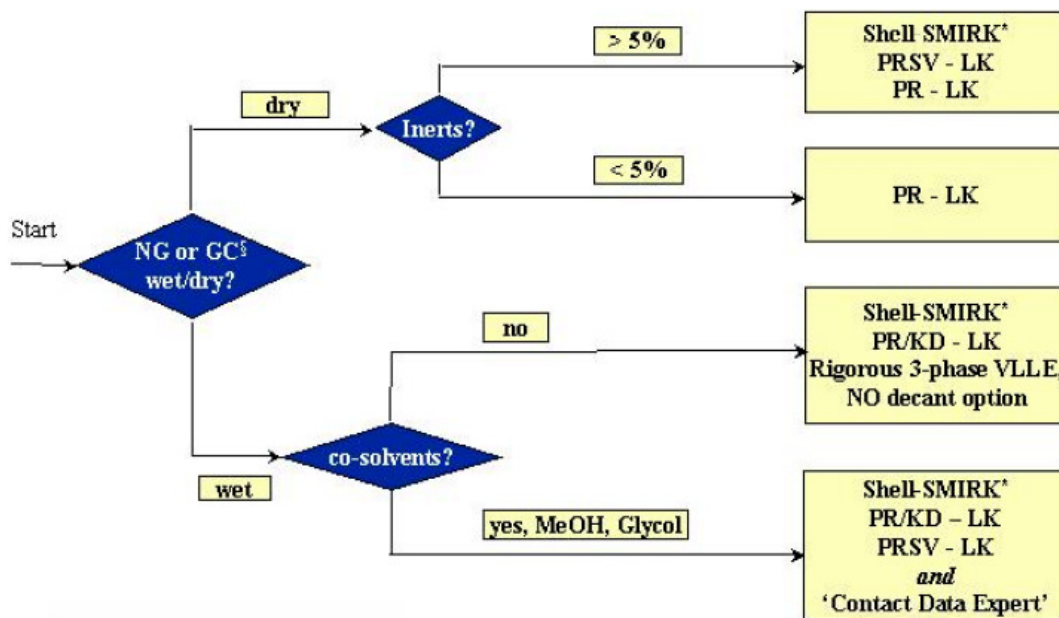
- Aspen HYSYS is the norm in the upstream Oil & Gas E&P application.
- Simsci PRO/II is widely used for downstream oil refining and processing application.
- Aspen Plus is widely used for petrochemical and chemical application process.

The simulation packages - HYSYS, PRO/II and Aspen Plus - provide help facilities to advise the user on thermodynamic system selection. This appears to be useful, but should not be considered infallible. It cannot replace a series of rational decisions based on understanding the nature of the simulation to be performed and knowledge of the various options available.

The accuracy required from a simulation is linked to the problem, the available input data, and importance of the decision that follows the simulation result.

The recommended methods made herein are for the normal day-to-day calculations performed by Process Engineers. For highly accurate calculations, the selected method needs to be validated with process licensor's and / or experimental data.

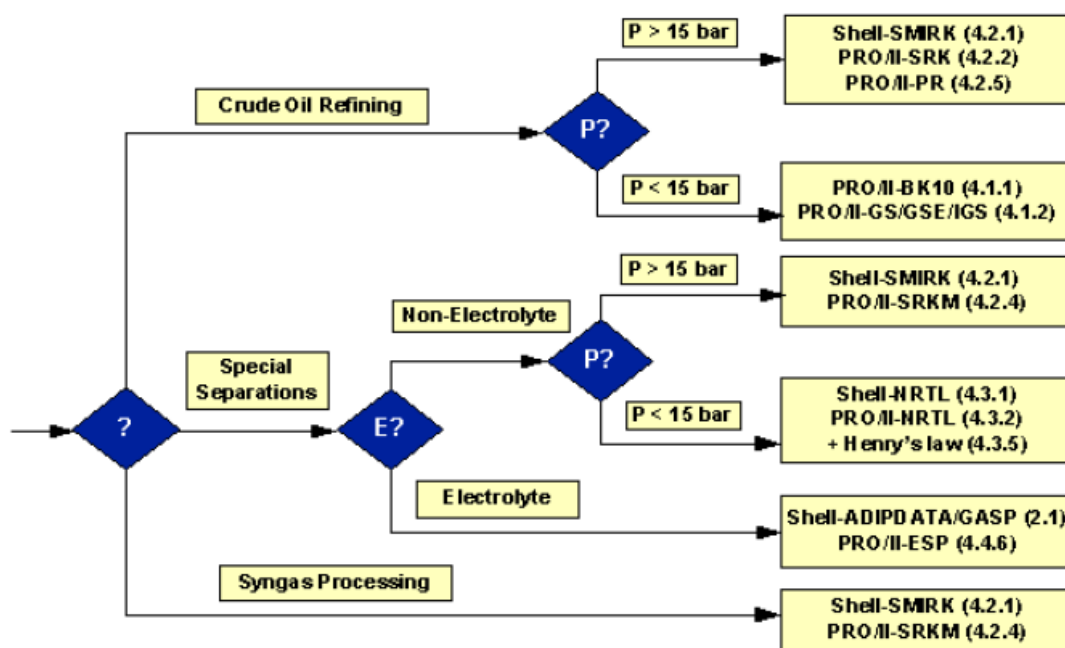
Physical property method selection *E&P applications using HYSYS*



*Shell-SMIRK via HYSPPPTS

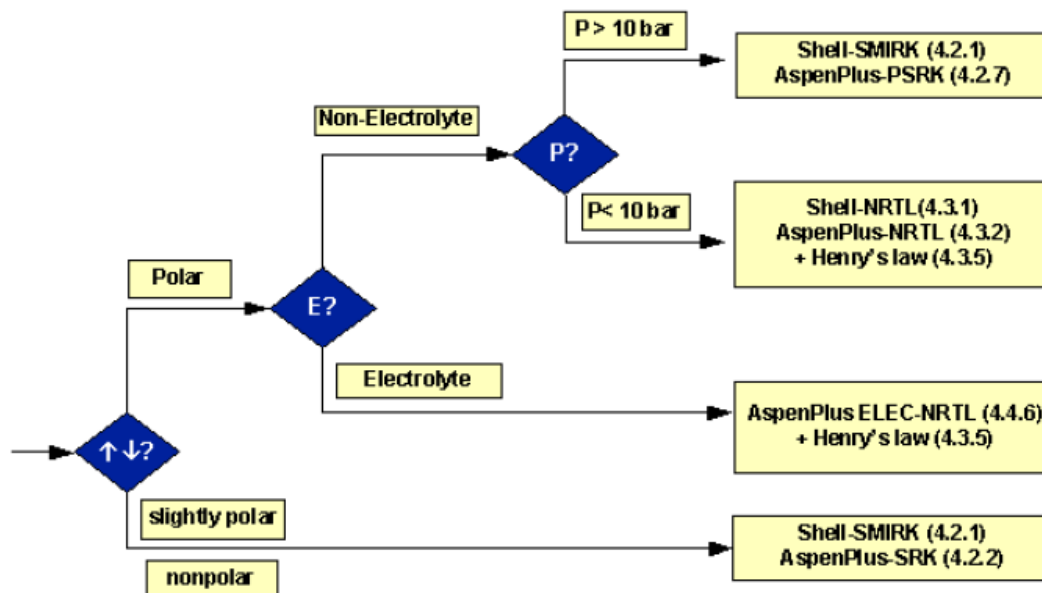
[‡] use special tools when freeze-out, gas-hydrates, wax, asphaltenes, scale,... are important

Physical property method selection *Downstream Oil applications using PRO/II*



Physical property method selection

Chemical applications using Aspen Plus



Further Reference:

1. Manuals and guides of simulation software packages HYSYS, PRO/II, ASPEN PLUS.

Key Process Activity:

13. Flow Assurance Evaluation

Following are the widely used software packages for flow assurance evaluation of pipelines.

Baker & Jardine PIPESIM: This is a steady state multi-phase pipeline network simulation package which includes descriptions of well performance and simple process facilities.

Scandpower OLGA2000: This is a transient simulator for multiphase pipelines and networks, which includes descriptions of well performance and simple process facilities. Can simulate three phases (gas, oil, water), and has special feature for slug tracking of Gas / liquid slugs.

The hydraulic analysis shall take full account of possible changes in flowrates and operational modes, over the complete operational life of the pipeline.

The hydraulic analysis should also address:

- surge pressure of a liquid line during inadvertent shut-down of a downstream valve;
- turn-down limitations and inhibition or insulation requirements to prevent wax or hydrates deposition;
- flow conditions, to allow their effect on the efficiency of corrosion inhibitors to be determined;
- benefit of internal coating after allowing for possible deterioration in coating during operational lifetime e.g. as a result of routine pigging;
- liquid catching and slug control requirements at the downstream end of two phase lines.

Further Reference:

1. e-BMS Guide: "Pipelines", [PEC-BMS-EN-GDE-P-2545](#)
 2. Manuals and guides of simulation software packages PIPESIM & OLGA.
-

Key Process Deliverable:

14. Process Flow Diagram (PFD) and Heat & Mass Balance (H&MB)

A PFD is a schematic drawing of a process or utility unit used for developing a clear understanding of the processing requirements. The PFD shows relevant physical and process data (identified with stream number), the main utilities, the basic control elements and the main processing equipment:

PFD shall include:

- Major equipment, (items such as compressor auxiliaries are not normally shown, equipment operating in the same service whether in parallel or series shall be shown as one unit, all spare equipment shall be omitted)
- Main processing lines including utilities
- Controls indicated by a simplified symbolic representation of control loops
- SDV's and ESDV's
- Heat and Material Balance (this may be submitted as a separate document)

Further Reference:

1. e-BMS Guide: "Process Flow Diagrams & Material Selection Diagrams", [PEC-BMS-EN-GDE-P-1757](#)
 2. Shell DEP: "Preparation of process flow schemes and process engineering flow schemes" [DEP 01.00.02.11-Gen.](#)
-

Key Process Deliverable:

15. Piping and Instrumentation Diagram (P&ID)

P&ID is a pictorial representation of a process or utility unit and has more detail than a PFD and shows all the equipment, including installed spares and the associated piping and piping components, instrumentation, heat tracing and insulation.

P&ID is intended to summarize the design requirement, safe operation and maintainability of the facility. It illustrates the scope of work, serves as a basic control document between Process and other disciplines, and provides the detailed design definition required for engineering and construction of process plant.

Equipment shall be identified by tag number and description, design pressure, design temperatures etc. Equipment shall be shown in realistic proportions, i.e., with pumps at the bottom and air coolers at the top of the P&ID. All piping and piping components shall be shown with their sizes, piping class and tag numbers. All instruments, both automatic control loops and manual controls, alarms and trip systems are to be shown.

Symbols and Legend sheets shall accompany each set of P&IDs.

Equipment, piping and instrument numbering should logically follow the process flow and also preferably be from left to right and from top to bottom on vertical equipment, except for column trays.

The P&IDs shall also show specific engineering requirements necessary for the design, e.g. sloping lines, minimum straight pipe lengths, equipment elevations, no pockets, enter at top of line, minimum or maximum distances etc. These requirements must be stated in words (or by a symbol) as P&IDs are not isometric representations.

Process conditions and physical data shall not be shown on the P&IDs.

Further Reference:

1. *e-BMS Guide: "Piping and Instrument Diagrams", [PEC-BMS-EN-GDE-P-1758](#)*
 2. *Shell DEP: "Preparation of process flow schemes and process engineering flow schemes" [DEP 01.00.02.11-Gen.](#)*
-

Key Process Activity:

16. Line Sizing

Line sizing is usually done with respect to pressure drop and velocity criteria. The procedure is that the line size is first selected based on the velocity criteria, and then it is checked against the pressure drop criteria. However, engineering judgment can be used when selecting line sizes, based on past experience of similar facilities.

The following should be considered in determining a suitable pipe size:

- The allowable pressure drop (including fittings).
- Whether pressure surges could occur in the piping system.
- Whether erosion could occur in the piping system.
- Whether the piping system could be subjected to vibrations (multiphase flow, connected heavy rotary equipment etc.).
- Whether solids could settle out from the fluid (e.g. slurry service or contaminants).
- The type of flow pattern of two-phase flow; an intermittent flow pattern shall be avoided.
- The allowable temperature drop if the fluid is highly viscous.
- The economic pipe diameter, considering the capital expenditure and operating expenditure of the pumps, compressors and the piping system.
- Mechanical strength.

The above considerations shall be taken into account both for the design capacity and for conditions such as starting up, shutting down and regeneration.

Refer the below e-BMS guide and spreadsheet for further sizing details.

Further Reference:

1. e-BMS Guide: “Line Sizing Philosophy”, [PEC-BMS-EN-GDE-P-1756](#)
 2. e-BMS Spreadsheet: “Line Hydraulics Calculation”, [PEC-BMS-EN-VSS-P-2550](#)
 3. Shell DEP: “Piping - general requirements”, [DEP 31.38.01.11-Gen.](#)
-

Key Process Activity:

17. Pump Hydraulics Calculation

The most common types of pumps used in processing plants are centrifugal and positive displacement. Modern practice is to use centrifugal rather than positive displacement pumps where possible because they are usually less costly, require less maintenance, and less space.

The following procedure is recommended to calculate the head of most pump services.

1. Prepare a sketch of the system in which the pump is to be installed, including the upstream and downstream vessels. Include all components which might create frictional head loss (both suction and discharge) such as valves, orifices, filters, and heat exchangers.
2. Show on the sketch:
 - The datum position (zero elevation line) according to the proper standard.
 - The pump nozzle sizes and elevations.
 - The minimum elevation (referred to the datum) of liquid expected in the suction vessel.
 - The maximum elevation (referred to the datum) to which the liquid is to be pumped.
 - The head loss expected to result from each component which creates a frictional pressure drop at design capacity.
3. Convert all the pressures, frictional head losses, and static heads to consistent units (usually kPa or meters of head). In 4 and 5 below, any elevation head is negative if the liquid level is below the datum. Also, the vessel pressures are the pressures acting on the liquid surfaces. This is very important for tall towers.
4. Add the static head to the suction vessel pressure, and then subtract the frictional head losses in the suction piping. This gives the total pressure (or head) of liquid at the pump suction flange.
5. Add the discharge vessel pressure, the frictional head losses in the discharge piping system, and the discharge static head. This gives the total pressure (or head) of liquid at the pump discharge. In order to provide good control, a discharge control valve should be designed to absorb at least 30% of the frictional head loss of the system, at the design flow rate.
6. Calculate the required pump total head by subtracting the calculated pump suction total pressure from the calculated pump discharge total pressure and converting to head.
7. It is prudent to add a safety factor to the calculated pump head to allow for inaccuracies in the estimates of heads and pressure losses, and pump design. Frequently a safety factor of 10% is used, but the size of the factor used for each pump should be chosen with consideration of:
 - The accuracy of the data used to calculate the required head
 - The cost of the safety factor
 - The problems which might be caused by installing a pump with inadequate head.

An important factor in pump operation is that, there should be sufficient net positive suction head available (NPSHA) for the pump to work properly without cavitation throughout its expected capacity range. Cavitation causes noise, impeller damage, and impaired pump performance. Consideration must also be given to any dissolved gases which may affect vapor pressure.

NPSHA is calculated as the total suction absolute head at the suction nozzle referred to the standard datum, minus the liquid vapor absolute pressure head at flowing temperature available for a specific application. NPSHA depends on the system characteristics, liquid properties and operating conditions.

NPSHR is the minimum total suction absolute head at the suction nozzle referred to the standard datum, minus the liquid vapor absolute pressure head at flowing temperature required to avoid cavitation. NPSHR depends on the pump characteristics and speed, liquid properties and flow rate and is determined by vendor testing, usually with water. For a given pump, NPSHR increases with increasing flow rate.

The NPSHA shall exceed the NPSHR by at least 1 m throughout the range from minimum continuous stable flow up to and including the rated capacity, and by 0.3 m at 120 % of rated flow. If the suction pressure at the pump is less than atmospheric, this margin shall be at least 2 m.

For liquids containing dissolved gases, to avoid cavitation damage due to vapor-induced flow path restrictions, NPSHA shall be 1.5 x NPSHR, with a minimum margin of 5 m between NPSHA and NPSHR.

Further Reference:

1. e-BMS Spreadsheet: "Pump Hydraulics Calculation" [PEC-BMS-EN-VSS-P-2554](#)
 2. Shell DEPs:
 - "Pumps - type selection and procurement procedure", [DEP 31.29.02.11](#)
 - "Centrifugal pumps (amendments/supplements to ISO 13709:2003)", [DEP 31.29.02.30](#)
 - "Centrifugal submerged motor pumps (in refrigerated product or pressurized storage service)", [DEP 31.29.06.30](#)
 - "Data Sheet - Centrifugal pumps", [DEP 31.29.02.93](#)
-

Key Process Activity:

18. Vessel Sizing

The three main types of process vessels commonly used are,

- Liquid surge drums
- Vertical gas-liquid separators
- Horizontal gas-liquid separators

1. Liquid surge drums: These are used to provide storage or surge capacity for liquid streams which are substantially free of vapor. These include reflux drums, feed surge drums, drain vessels and may be either horizontal or vertical configuration.
2. Vertical Gas-Liquid Separators: Its main function is to separate vapor-liquid mixtures and deliver substantially liquid-free vapor to the process. They are generally preferred for handling mixtures with high vapor/liquid mass flow ratio and are usually with only a single liquid phase. These include Compressor suction KO drums, Fuel gas scrubber, Flash vessels etc.

Other influencing factors for selecting vertical orientation are:

- a smaller plan area is required (critical on offshore platforms);
- easier solids removal;
- liquid removal efficiency does not vary with liquid level;
- vessel volume is generally smaller.

3. Horizontal Gas-Liquid Separators: These are preferred to handle mixtures with low vapor/liquid mass flow ratio and also mixtures containing more than one liquid phase. The typical applications are Oil Inlet Separators, Steam drums, Blowdown drums, Flare KO drums etc.

Other influencing factors for selecting horizontal orientation are:

- large liquid slugs have to be accommodated;
- head room is restricted;
- a low downward liquid velocity is required.

The sizing procedures and spreadsheets have been developed and design recommendations are available for these three types of vessels. Refer the below e-BMS guide and spreadsheets for further sizing details.

Further Reference:

1. e-BMS Guide: “Vessel Sizing Criterion”, [PEC-BMS-EN-GDE-P-2543](#)
2. e-BMS Spreadsheets:
 - “Surge Drum Sizing”, [PEC-BMS-EN-VSS-P-2561](#)
 - “Vertical KO Drum (Gas / Liquid Separator)”, [CHE-BMS-EN-VSS-P-2822](#)
 - “Vertical Separator Sizing - Shell DEP”, [PEC-BMS-EN-VSS-P-2555](#)
 - “Vertical Separator Sizing (API 12J)”, [PEC-BMS-EN-VSS-P-2553](#)
 - “Horizontal Separator Sizing (API 12J)”, [PEC-BMS-EN-VSS-P-2552](#)
 - “Condensate Drum Sizing”, [PEC-BMS-EN-VSS-P-2560](#)
 - “Flare KOD Sizing”, [PEC-BMS-EN-VSS-P-2559](#)
 - “Tank Capacity Check”, [PEC-BMS-EN-VSS-P-2562](#)
3. Shell DEPs:

- “Gas/liquid separators - Type selection and design rules”, DEP [31.22.05.11-Gen.](#)
 - “Liquid/liquid and gas/liquid/liquid separators - Type selection and design rules”, DEP [31.22.05.12-Gen.](#)
 - “Data Sheet - Pressure Vessels (columns, reactors, accumulators etc.)”, DEP [31.22.00.94](#)
4. API Std.: “Specification for Oil and Gas Separators”, API Spec. 12J
-

Key Process Activity:

19. Heat Exchanger Thermal Design

The three main types of heat exchangers commonly used in process are,

- Shell and Tube Heat Exchanger
- Air-cooled Heat Exchangers
- Plate and Frame Heat Exchangers

The thermal design of a process heat exchanger usually proceeds through the following steps:

1. Process conditions (stream compositions, flow rates, temperatures, pressures) must be specified for the required service.
2. Required physical properties over the temperature and pressure ranges of interest must be obtained.
3. The type of heat exchanger to be employed is chosen.
4. A preliminary estimate of the size of the exchanger is made, using a heat-transfer coefficient appropriate to the fluids, the process, and the equipment.
5. A first design is chosen, complete in all details necessary to carry out the design calculations.
6. The design chosen in step 5 is evaluated, or rated, as to its ability to meet the process specifications with respect to both heat transfer and pressure drop.
7. On the basis of the result of step 6, a new configuration is chosen if necessary and step 6 is repeated. If the first design was inadequate to meet the required heat load, it is usually necessary to increase the size of the exchanger while still remaining within specified or feasible limits of pressure drop, tube length, shell diameter, etc. This will sometimes mean going to multiple-exchanger configurations. If the first design more than meets heat load requirements or does not use the entire allowable pressure drop, a less expensive exchanger can usually be designed to fulfill process requirements.
8. The final design should meet process requirements (within reasonable expectations of error) at lowest cost. The lowest cost should include operation and maintenance costs and credit for ability to meet long-term process changes, as well as installed (capital) cost. Exchangers should not be selected entirely on a lowest-first-cost basis, which frequently results in future penalties.

The thermal design and rating of heat exchangers shall be based on design methods which have been proven in practice. In this respect, the following design procedures and computer programs are considered to be proven for each type of exchanger.

1. Shell and Tube Heat Exchanger:

- Heat Transfer Research Inc. (HTRI), "Xist" program;
- Heat Transfer and Fluid Flow Service (HTFS), "TASC" program.

In the event of inadequate performance, the HTRI Xist program shall be used as the basis for re-assessing the thermal performance rating.

The computer programs used for the thermal design of the heat exchangers contain routines to check the likelihood of mechanical and/or acoustic vibrations. The thermal designer shall analyze the vibration warnings generated

by the program and take adequate measures to prevent such vibration. In the event of disagreements about vibration, the HTRI computer program VIB shall be used as a basis for assessing tube vibration.

2. Air-cooled Heat Exchangers:

- ACOL developed by HTFS
- ACE developed by HTRI

In the event of inadequate performance, the HTFS ACOL program shall be used as the basis for re-assessing the thermal performance rating.

3. Plate and Frame Heat Exchangers

- XPHE developed by HTRI
- APLE developed by HTFS

Because plate-and-frame heat exchangers are proprietary designs, the Manufacturer shall be totally responsible for the performance of the exchanger.

Further Reference:

1. e-BMS Guide: "Shell and Tube Heat Exchangers", [PEC-BMS-EN-GDE-P-2563](#)
2. Manuals and guides of thermal design software packages HTRI & HTFS
3. Shell DEPs:
 - "Shell and tube heat exchangers (amendments/supplements to ISO 16812)", [DEP 31.21.01.30-Gen.](#)
 - "Air-cooled heat exchangers (amendments/supplements to ISO 13706)", [DEP 31.21.70.31-Gen.](#)
 - "Plate and frame heat exchangers (amendments/supplements to ISO 15547)", [DEP 31.21.01.32-Gen.](#)
 - "Fouling resistances for heat transfer equipment", [DEP 20.21.00.31-Gen](#)
 - "Data Sheet - Shell-and-tube heat exchangers", [DEP 31.21.00.93](#)
 - "Data Sheet - Air-cooled heat exchangers", [DEP 31.21.70.93](#)
 - "Data Sheet - Plate heat exchangers", [DEP 31.21.01.93](#)
4. API Standards:
 - "Shell-and-Tube Heat Exchangers for General Refinery Services", API Std. 660
 - "Air-Cooled Heat Exchangers for General Refinery Service", API Std. 661
 - "Plate Heat Exchangers for General Refinery Services", API Std. 662
5. ISO Standards:
 - "Petroleum and natural gas industries - Shell-and-tube heat exchangers", ISO 16812
 - "Petroleum and natural gas industries - air-cooled heat exchangers", ISO 13706
 - "Petroleum and natural gas industries - Plate-and-frame heat exchangers", ISO 15547
6. Standards of the Tubular Exchanger Manufacturers Association (TEMA)

Key Process Activity:

20. Relief Valve Sizing

Pressure relief valves or other relieving devices are used to protect piping and equipment against excessive over-pressure. Proper selection, use, location, and maintenance of relief devices are essential to protect personnel and equipment as well as to comply with codes and laws.

The design of the proper relieving device must take into consideration all of the following upset conditions for the individual equipment item if such upset can occur. Each upset condition must be carefully evaluated to determine the "worst case" condition which will dictate the relieving device capacity. The simultaneous occurrence of two or more unrelated causes of overpressure (also known as double or multiple jeopardy) is not a basis for design.

Following are the principal causes of overpressure and shall be used as guide for determining the relief capacity requirement.

- Closed outlets or Blocked Discharge while the equipment is on-stream.
- Inadvertent valve opening from a source of higher pressure.
- Check-valve failure leading to reverse flow from a high-pressure source.
- Utility failure (Electric, Cooling water / medium, instrument air, steam / heating medium, fuel, inert gas etc.)
- Abnormal heat input from reboilers.
- Heat exchanger tube failure.
- Transient pressure surges (water hammer, steam hammer, Condensate-induced hammer)
- Thermal Expansion
- Plant Fire
- Process changes/chemical reactions

After the required relief capacity of a relief valve has been determined, the minimum relief valve orifice size required must be calculated. Industry standard for relief valve orifice area, orifice designation, valve dimensions, valve body sizes, and pressure ratings are available.

For calculations of the relief valve size for single-phase flow, the formulae in API RP 520 shall be applied.

For two-phase flow relieving conditions if liquid is released above bubble point pressure, the methods specified in API RP 520 Appendix D may be used. If more data are available a more rigorous approach using vapor/liquid equilibrium (VLE) models based on Homogeneous Equilibrium Model (HEM) as detailed in Shell DEP 80.36.00.30-Gen. shall be used.

In order to ensure safe relief, certain factors shall be taken into consideration when designing the pipework upstream and downstream of the relief device.

Piping upstream of a relief device should be designed with as few restrictions to flow as possible and should not be pocketed. Excessive pressure loss at the inlet of a pressure-relief valve can cause rapid opening and closing of the valve, or chattering. The pressure drop of the piping between the protected equipment and its relief valve shall not exceed 3% of the set pressure. Exceptions to this requirement are only allowed in the case of a pilot-operated valve.

The discharge piping system should be designed so that the back pressure does not exceed an acceptable value for any pressure relief device in the system. Once the maximum design load on each header and sub-header has been ascertained it is possible to size the downstream piping system. By starting from the tip of the flare or vent stack where the pressure is atmospheric, and adding each calculated pressure drop, the built-up back pressure downstream of each relief or depressurizing device can be determined.

Selection of Relief valve type is done based on the following criteria of maximum allowable back pressure.

- Variable back pressure < 10% of set pressure; use non balanced spring loaded relief valves.
- Variable back pressure < 21% of set pressure for fire cases and applying equipment following ASME VIII; use non balanced spring loaded relief valves.
- Variable back pressure < 50% of set pressure; use balanced-bellows spring-loaded relief valves.
- Variable back pressure < 70% of set pressure; use pilot-operated relief valves.

Further Reference:

1. API Standards:
 - “Sizing, Selection, and Installation of Pressure-Relieving Devices in Refineries”, API RP 520 Part I & II.
 - “Pressure-relieving and Depressurizing Systems”, API 521.
 - “Flanged Steel Pressure Relief Valves”, API 526.
 2. Shell DEPs:
 - “Relief valves - selection, sizing and specification”, [DEP 80.36.00.30](#)
 - “Pressure relief, emergency depressurizing, flare and vent systems”, [DEP 80.45.10.10](#)
 - “Safety/relief valve calculation sheet”, [DEP 31.36.90.94](#)
 - “Safety relief valve calculation sheet for two-phase flow”, [DEP 31.36.90.95](#)
 3. Spreadsheets for reference only (Uncontrolled):
 - Relief Load Calculation [Spreadsheet](#)
 - Relief Valve Sizing [Spreadsheet](#)
-

Key Process Activity:

21. Blowdown and Depressurization Study

A relief valve installed on a vessel or system can only limit the pressure rise to the set point during upset or emergency conditions. However, a fire can heat equipment or piping walls to temperatures higher than design, and hence the pressure must be reduced in order to lower the stress. The pressure shall be reduced by using a high rate emergency vapor depressurizing system actuated by operator action. Remote actuation shall be possible from a safe distance, usually the control room. Blowdown is carried out using restriction orifice plates located downstream of remotely actuated Blowdown Valves (BDV's).

The operating facilities are divided into isolatable sections by the use of tight shut off Emergency Shutdown Valves (ESV's) activated by the Emergency Shutdown (ESD) system.

Blowdown facilities are provided on all isolatable sections of hydrocarbon gas or both gases and liquids operating above a pressure of 17 barg (according to API RP521) and/or containing more than 4 m3 of butane or more volatile liquid, such that they can be individually depressurized following a shutdown.

In general all sections requiring blowdown must be isolated and depressurized to half their design pressure or 6.9 barg, whichever is lower in 15 minutes under external fire conditions (according to API RP 521). The DEP's differ in this philosophy and depressurization up to 50% of the design pressure only is specified (ref DEP 80.45.10.10).

However, when these criteria lead to excessively large blowdown systems and in particular if it becomes the sizing case for the flare system a more detailed risk assessment should be carried out to optimize the blowdown time and/or target pressure.

If the overall peak blowdown loads exceed the design of the flare systems then consideration shall be given to sectionalisation. Sectionalisation is a philosophy applied to split an installation into a number of fire zones with peak blowdown rates below the design loads of the flare systems. Each zone contains one or more isolatable process systems with blowdown facilities, such that each zone can be depressurized sequentially, thereby reducing the design peak blowdown load.

Further Reference:

1. *e-BMS Guides:*
 - “Blowdown & Depressurisation”, [PEC-BMS-EN-GDE-P-2547](#)
 - “Depressurisation using Hysys”, [PEC-BMS-EN-GDE-P-2548](#)
2. Shell DEP: “Pressure relief, emergency depressuring, flare and vent systems”, [DEP 80.45.10.10](#)
3. API Std.: “Pressure-relieving and Depressurizing Systems”, API 521

Key Process Activity

22. Flare Design

The primary function of a flare is to use combustion to convert flammable, toxic or corrosive vapors to less objectionable compounds.

Following major factors govern the sizing of flares.

1. Flare-stack diameter is generally sized on a velocity basis, although pressure drop should be checked. It can be desirable to permit a velocity of up to 0.5 Mach for a peak, short-term, infrequent flow, with 0.2 Mach maintained for the more normal and possibly more frequent conditions for low-pressure flares.
2. The flare-stack height is generally based on the radiant-heat intensity generated by the flame. The height of the flare stack shall be selected to meet the following conditions:
 - The sterile area radius should be 60 m.
 - At the boundary of the sterile area the heat radiation level shall be 6.3 kW/m² maximum (excluding the effect of solar radiation *).
 - At the property limit the heat radiation level shall be 3.15 kW/m² maximum (excluding the effect of solar radiation *).

* API 521 states that the solar-radiation-contribution adjustment to the radiation level values may be considered on a case-by-case basis. However, Shell DEP 80.45.10.10 state to exclude the effect of solar radiation and the addition is considered not to be realistic.
3. Another factor influencing flare-stack height is the effect of wind in tilting the flame, thus varying the distance from the centre of the flame, which is considered to be the origin of the total radiant-heat release.
4. The concern about the resulting atmospheric dispersion if the flare were to be extinguished also influences flare-stack height. Dispersion shall be such that within the hazardous contour (the area within which either an ignition source or personnel could be present),
 - The concentration of flammable components is less than the lower flammability limit.
 - The concentration of toxic components is less than the TLV-TWA (Threshold Limit Value - Time Weighted Average).
5. No noticeable stench or irritation levels shall be caused outside the property limits. Proper operation of the flare (combustion efficiency > 98%) may be assumed.
6. Noise limits shall be complied.
 - For emergency conditions, the noise level at the base of the stack shall not exceed 115 dB(A). If the stack is provided with a derrick structure, including a platform for coupling/uncoupling segments of the retractable stack, the noise limit applies to this platform.
 - For normal operation (including starting-up and shutting-down), the noise levels at the perimeter of the sterile area shall not exceed 85 dB(A) at flow rates up to 15% of maximum flaring capacity or at the maximum relief rate that may occur during normal operation (including starting-up and shutting-down), whichever is the higher.

Smoke-free operation of flares can be achieved by various methods, including steam injection, injection of high-pressure waste gas, forced draft air etc.

One of the most common methods of preventing propagation of flame into the flare system as a result of the entry of air is to install a seal drum. The continuous introduction of purge gas at an adequate rate is also used to reduce the possibility of flashback with or without a seal drum. Flame arresters are seldom used in a flare system for flashback protection because they are subject to plugging.

Further Reference:

1. API Stds.:
 - “Pressure-relieving and Depressurizing Systems”, API 521
 - “Flare Details for General Refinery and Petrochemical Service”, API 537
 2. Shell DEP: “Pressure relief, emergency depressurizing, flare and vent systems”, [DEP 80.45.10.10](#)
-