Cairo University
faculty of Engineering
Department of Chemical Engineering

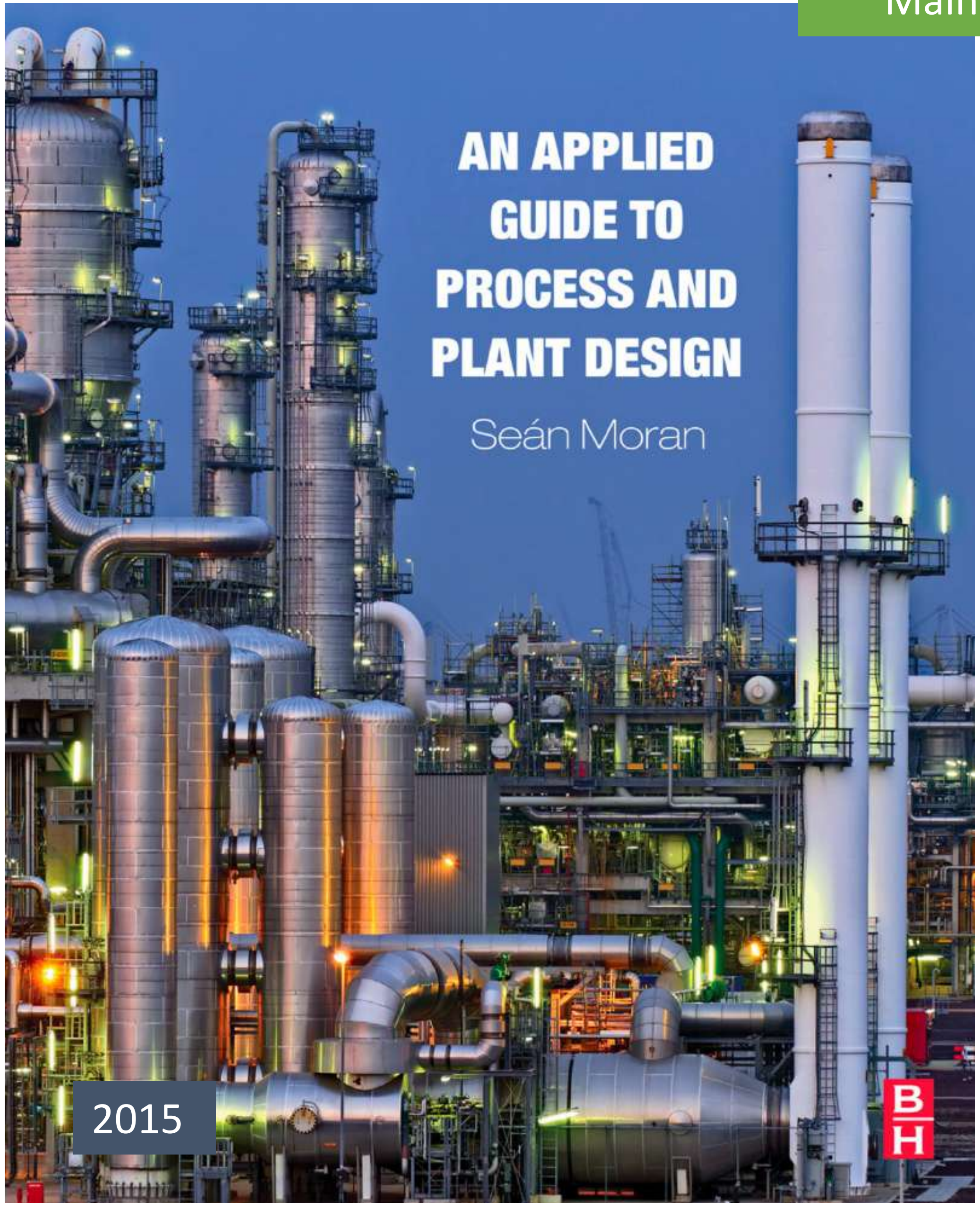
Process and Plant Design

Introducing the two Moran’s Books

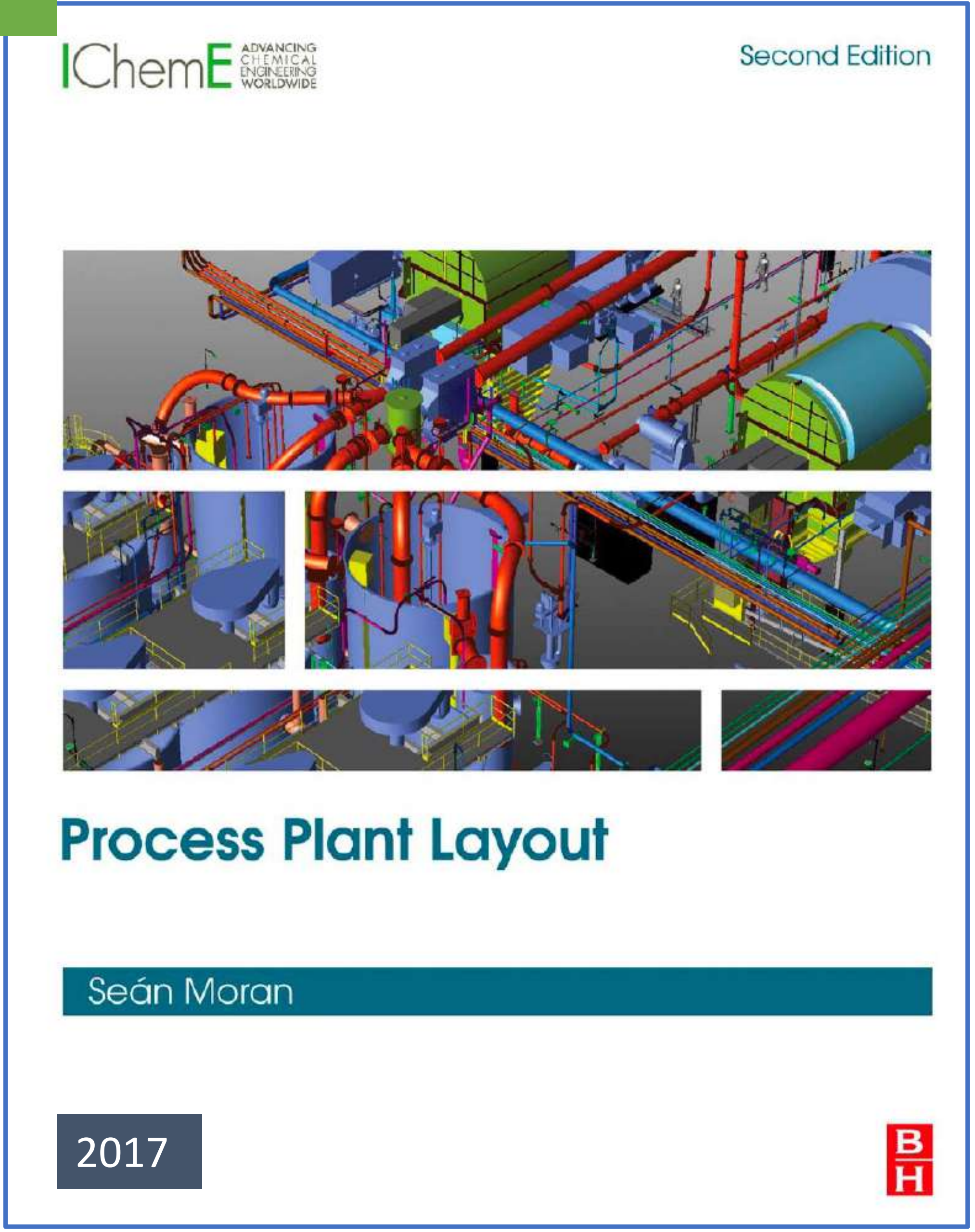
Ahmed Gaber - October 2018

Engineers Conceive, Design, Implement, and Operate (CDIO) engineering solutions

Main Sources



2015



2017

Outline

Project Life Cycle

Design Stages

Professional Engineering Tools

Process Plant Design Deliverables

Project Life Cycle

Project Life Cycle

1. Identify the problem: this stage is frequently overlooked because people think they know what the problem is.

2. Define the problem in business, engineering, and scientific terms: often done poorly with the problem again being defined in terms of perceived solutions.

3. Generate options: that provide potential solutions to the problem.

"Options" البدائل – هذه الكلمة السحرية

(Cont'd.) Project Life Cycle

4. Review the options against agreed selection criteria and eliminate those options that clearly do not meet the selection criteria.

5. Generate the outline process design for the selected options.

6. In parallel:

   a. Commence development work at laboratory scale to provide more data to refine the business, engineering, and scientific basis of the options.

   b. Commence an engineering project to evaluate the possible locations, project time scale, and order of magnitude of cost.

   c. Develop the "business case" at the strategic level.

(Cont'd.) Project Life Cycle

7. Based on the outcomes of step 6, **reduce the number** of options to those carried forward to the next level of detail.

8. In parallel:

a. Continue the work at the pilot plant scale.

b. Based initially on the data from the laboratory scale, develop the concept design of the remaining options to allow a rough capital cost estimate to be generated and a refined project time scale.

c. Continue to develop the "business case" leading to a project sanction request at the appropriate corporate level.

(Cont'd.) Project Life Cycle

9. Based on the outcomes of step 8, **select the lead option** to be designed and installed.

10. In parallel:

a. Continue the development work at the pilot scale.

b. Carry out the detailed design of the lead option. A "design freeze" will almost certainly need to occur before the development work is complete.

11. Construct the required infrastructure, buildings, etc. and install the required equipment.

12. Commission the equipment.

(Cont'd.) Project Life Cycle

13. Commission the process and verify that the plant performs as designed and produces product of the required quality.

14. Commence routine **production**.

15. **Improve process efficiency** based on the data and experience gained during routine production.

16. **Increase the plant capacity** by making use of process improvements and optimization based on the data and experience gained.

17. **Decommission** the plant at the end of the product life cycle.

Summary of the project life cycle

	Start point	End point	Specific target
Stage One	An idea	Agreement that this is a project which meets a business need	Determine the link between the project and the business, confirm the project scope which will enable the business benefits
Stage Two	An approved project (approval to develop a plan)	An approved project delivery plan	Determine the most appropriate way to deliver the project scope to meet the business needs. Ensure that the business plans to receive the project
Stage Three	An approved project (approval to deliver)	A successfully delivered project	Deliver the appropriate project scope in control
Stage Four	A delivered project	Sustainably delivered benefits	Deliver the required business benefits sustainably. Integration of any business changes caused by the project

Source: Melton, PM Toolkit, 2007

Design Stages

Design Stages

Design is nominally a five-stage process:

1. Conceptual: before design sanction
2. FEED (Front End Engineering Design) after design sanction
3. Detailed: before project sanction
4. “For Construction”: after project sanction
5. “Post Construction”: after project handover

Definitions:

Sanction: Permission to proceed to the next stage of design, usually with a formal form of contract and accompanying promises of payment

Site: Defined as the whole area of process plant within the boundary fence, land in ownership, or bounded land within which a process plant sits

Site Layout: Layout at a site level: the consideration of plots in relation to one other within the site as well as activities outside the site

Layout within project design stages

- These five stages are used almost universally because the adverse consequences of not having accurate cost and hazard assessments will increase considerably at each successive project stage.
- The preliminary stages of layout involve conception, evaluation, and modification, with the last two being repeated until a satisfactory solution is achieved.
- Process and project experience remains the best basis for layout conception and modification, even though computers and their software applications have come a long way during the last 10 years.
- The designer assigned to detailed layout is also involved with project planning, increasingly so since the introduction of computers for planning control.

Professional Engineering Tools

Standards and Specifications

- Standards and specifications exist to keep design parameters in the range where the final plant is most likely to be safe and to work. They also serve to keep design documentation comprehensible to fellow engineers. A brilliant design which no one else understands is worthless in engineering.
- There are a number of international standards organizations—ISO in Europe, DIN in Germany, ANSI, ASTM, and API in the United States, and so on ("British Standards" in the United Kingdom are now officially a subset of ISO).
- We do not, for example, use 68.9 mm internal diameter pipe, we use 75 mm NB (nominal bore), because that is what is readily commercially available. NB and its US near-equivalent NPS (nominal pipe size) are themselves specifications, rather than sizes.

Design Manuals

- Companies frequently have in-house design manuals which are a formal way to share the company's experience of the processes it most often designs. These manuals are not in the public domain, because they contain a significant portion of the company's know-how.

- Some national and international standards are also essentially design manuals—for example, PD5500 used to be a British Standard and is now more of a design note or manual which reflects many years of experience of safe design of critical pieces of equipment (namely the unfired pressure vessel), despite being superseded in 2002 by a European standard (BS EN 13445).

Rules of Thumb

- Rules of thumb are a type of short-cut way and are usually very simple calculations which capture knowledge of what tends to work.
- Rules of thumb do not necessarily replace more rigorous analysis when it comes to detailed design, but their condensation of knowledge gained from experience provides a quick route to the "probably workable" region of the design space, especially at the conceptual design stage.
- Rules of thumb encapsulate experience and are therefore better than first principles design.

Approximations

- All is approximation in engineering. If you think you are precisely right, you are precisely wrong. Engineers who grew up in the era of the slide rule know that anything after the third significant figure is at best science, rather than engineering.
- We need to know how precise and certain we have to be in our answers in order to know how rigorous to be in our calculation. Very often, in troubleshooting exercises, knowing the usual interrelationships between a few measurements is all that is needed to spot the most likely source of problems.
- Coarse approximations will get us looking in the right general area for our answers.

القاعدة الذهبية للتقريب

Professional Judgement

- Douglas gives a figure in “Conceptual Design of Chemical Processes” of 10^5-10^8 possible variations for a new process plant design.
- An engineer’s professional judgment discards many options a beginner would waste time exploring and include options which beginners would be unlikely to think of. They will know which simple calculations will allow them to choose quickly between classes of solution.
- Consequently, experts can quickly achieve outcomes which less experienced practitioners might never arrive at. This judgment takes many years of practice to develop, but its development may be started in an academic setting, and Moran’s book is attempting to assist in this task.

Process Plant Design Deliverables

1. Design Basis and Philosophies

- The terms “design basis and design philosophy” are sometimes taken to be the same thing, but there are some differences between them.
- A **design basis** will usually be a brief (no more than a couple of sides of A4) written document which defines the broad limits of the FEED study, including such things as operating and environmental conditions, feedstock and product qualities, and the acceptable range of technologies.
- **Design philosophies**, by contrast, may run to 40 pages, and include details on issues such as overpressure protection philosophies, vent, flare, and blowdown philosophies and isolation philosophies.
- From a layout point of view, the design philosophies of a project for road, rail, and service layout, as well as buildings and construction requirements (including standards of protection against fire and explosion) need to be established.

(Cont'd.) Design Basis and Philosophies

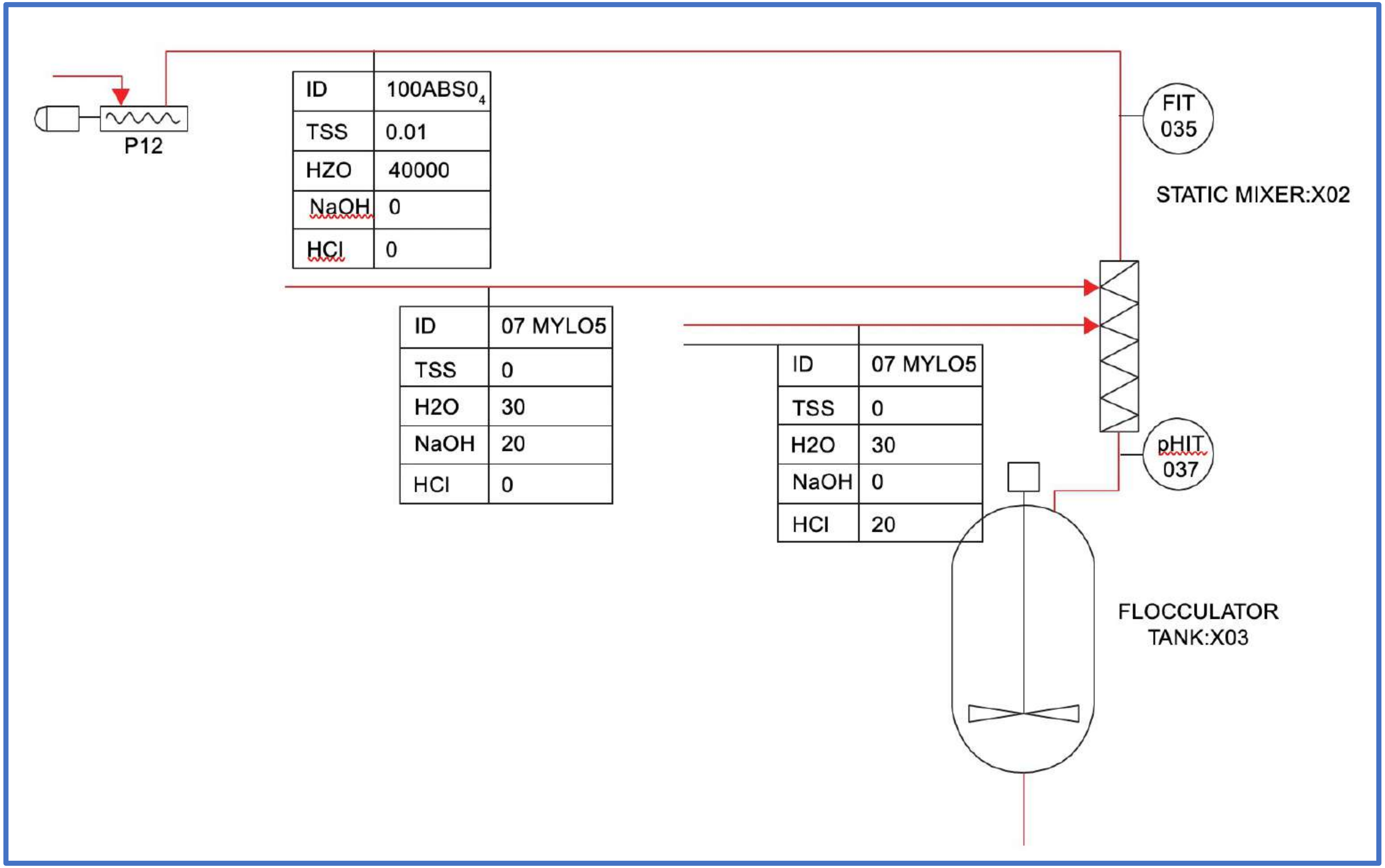
- Design philosophies for issues such as heights of pipe bridges, and where to use overhead or buried piping are decided partly from information provided by the site survey and are based on the relevant standards.
- Clients often specify a design philosophy in their documentation, and individual designers may have their own in-house approaches. It is good practice for a formal design philosophy to be written as one of the first documents on a design project.
- The design philosophy should specify the underlying assumptions and justifications for the choice.
- In the absence of a written design philosophy, a different engineer working at the detailed design stage might attempt to apply an alternative, and the plant may consequently become subject to expensive redesign.

2. Specifications

- Specifications are introduced at various stages of the design process which support the definition of the design package.
- The expected quantities and qualities of feeds into the process should be included, as well as a description of end-product quality and quantity. These descriptions will ideally be in the form of ranges of concentrations, flows, temperatures, pressures, and so on.
- There may be reference to specifically applicable standards and codes which are likely to be critical to this specific design.

3. Process Flow Diagram (PFD)

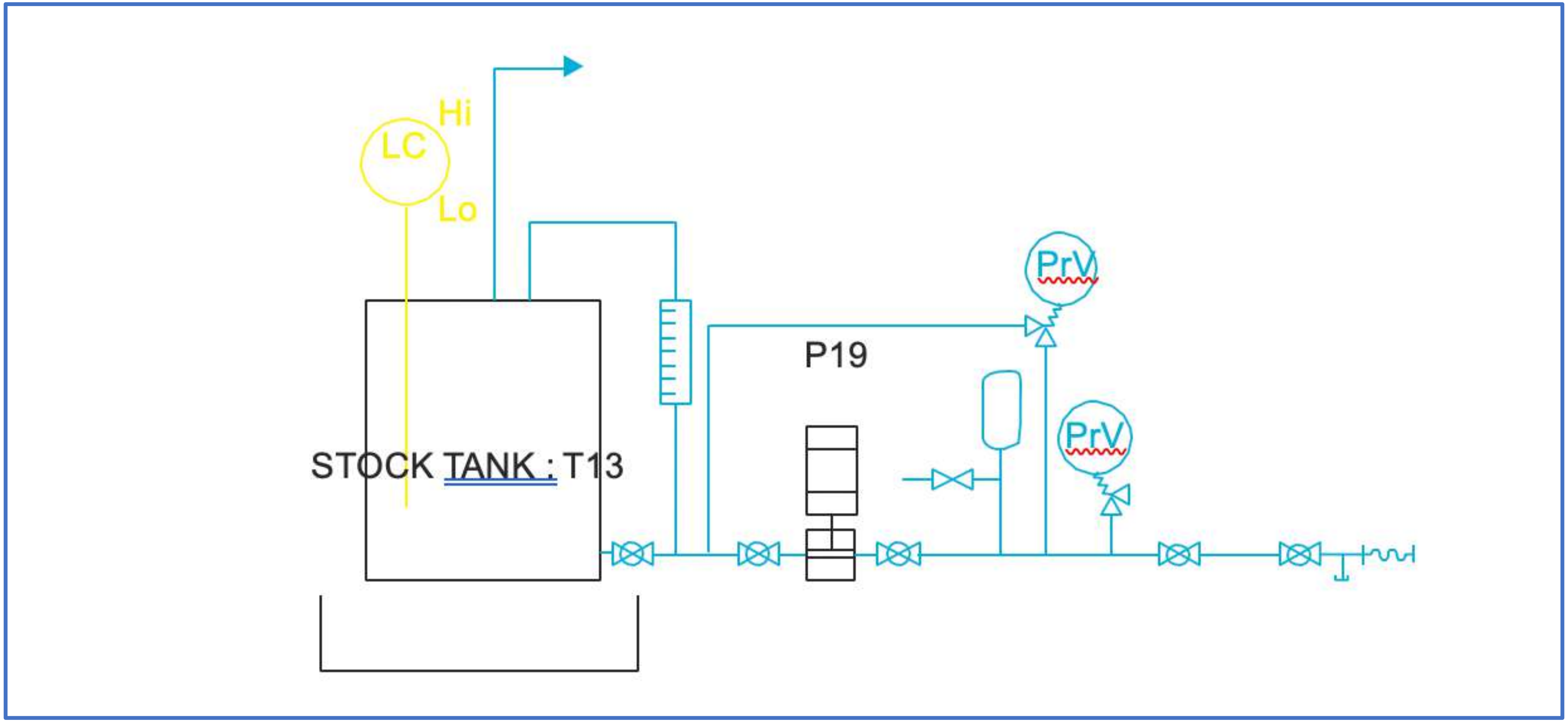
- The layout designer uses a PFD as the basis of initial plant layout. The order of unit operations on the PFD (usually from top left to bottom right of the drawing) is a good starting point for their layout in space.
- In the United Kingdom and Europe, the general British Standard for engineering drawings (BS 5070) applies to the PFD, as does BS EN ISO 10628. The symbols used on the PFD should ideally be taken from BS EN ISO 10628, BS1646, and BS1553. In the United States (and in industries influenced by US regulation, such as oil and gas), ANSI/ASME Y14.1 "Engineering Drawing Practice" and ANSI/ISA S5.1-1984 (R 1992) "Instrumentation Symbols and Identification" apply.
- The PFD treats unit operations more simply than the P&ID. Unit operations are shown using standard P&ID symbols or sometimes as simple blocks. Pumps are shown, as are main instruments, as shown in next slide.
- The lines on the PFD are labeled in such a way to summarize the mass and energy balance, with flows, temperatures, and compositions of streams. The visual representation of the plan interconnections and mass and energy balance is the main purpose of the drawing.



Process Flow Diagram (PFD) for pH correction section at a water treatment plant

4. Piping and Instrumentation Diagram (P&ID)

- The P&ID is a drawing which shows all instrumentation, unit operations, valves, process piping (connections, size, and materials), flow direction, and line size changes both symbolically and topologically. An example of an extract from a P&ID is shown in the next slide.
- The P&ID is the process engineer's most important document, which develops during the design process. Its purpose is to show the physical and logical flows and interconnections of the proposed system. Recording these visually on the P&ID allows them to be discussed with software engineers, as well as other process engineers. It is useful to the layout designer as it usually shows pipe sizes, materials, and other detailed features which do not appear on the PFD.



Extract from a piping and instrumentation diagram (P&ID)

Common P&ID Conventions

- Flow comes in on the top left of the drawing, and goes out on the bottom right
- Process lines are straight and either horizontal or vertical
- Flow direction is marked on lines with an arrow
- Flow proceeds ideally from left to right, and pumps, etc. are also shown with flow running left to right
- Sizes of symbols bear some relation to their physical sizes: valves are smaller than pumps, which are smaller than vessels, and the drawn sizes of symbols reflect this
- Unit operations are tagged and labeled
- Symbols are shown correctly orientated: vertical vessels are shown as vertical, etc.
- Entries and exits to tanks connect to the correct part of the symbol—top entries at the top of the symbol, etc.

5. Equipment List/Schedule

- A schedule or table of all the equipment which makes up the plant is usually first produced at FEED stage (See next slide). Tag numbers from drawings are used as unique identifiers, and a description of each item accompanies them. There may be cross-referencing to P&IDs, datasheets, or other schedules.

- Similar schedules are produced for all instrumentation, electrical drives, valves, and lines.

  Some modern software packages promise to remove the necessarily onerous task of producing these schedules from the junior engineer's task list. They are commonly generated from the databases created during P&ID development, or by 3D plant modeling software.

Form of Equipment Schedule

INSTRUMENT SCHEDULE

					Rev 0	Rev 1	Rev 2	Rev 3	Rev 4		
Project	Permanent Effluent/Groundwater Treatment Plant	Project Ref		Prepared by	SMM						
Project Site		Document Ref		Checked by	STM					CONFIRM	
Client				Date	30/04/2004						
Client Ref				Approved by							
				Date							

Inst No	Description	Supplier	Type	P&ID no	Line No	Size (mm)	Material of Constr	Design Fluid conditions		Operating range		Alarm conditions		Notes	CSL /Equip supplier
								Press (bar)	Temp (C)	Min	Max	H	L		
LC001	MH 102 (PS1) Level Controller	Milltronics	Ultrasonic	90501 002		n/a	proprietary	atmos	ambient	0	5000 mm	Y	Y	Milltronics Multiranger with 2 sensors in sump, panel mounted indicator. Some alarms from PLC	CSL
PI002	Pressure Indicator	TBA	Bourdon	90501 002	0056	tbc	SS enclosure	5	ambient	0	2 bar	N	N	Standard 50/75/100 mm pressure gauge	CSL
PTx003	Pressure Transmitter	GEMS	Transducer	90501 002	0056	n/a	316 ss	6	ambient	0	2 bar	Y	Y	Pressure transmitter and panel mounted indicator	CSL
FTx004	Flow Transmitter	ABB	Electromagnetic	90501 002	0056	300	proprietary	16	ambient	0	120 m3/hr	Y	Y	AB Magmaster inline meter with panel mounted display	CSL
LC005	MH 92A (PS2) Level Controller	Milltronics	Ultrasonic	90501 002		n/a	proprietary	atmos	ambient	0	5000 mm	Y	Y	Milltronics Multiranger with 2 sensors in sump, panel mounted indicator. Some alarms from PLC	CSL
PI006	Pressure Indicator	TBA	Bourdon	90501 002	0062	tbc	SS enclosure	5	ambient	0	2 bar	N	N	Standard 50/75/100 mm pressure gauge	CSL
PTx007	Pressure Transmitter	GEMS	Transducer	90501 002	0062	n/a	316 ss	6	ambient	0	2 bar	Y	Y	Pressure transmitter and panel mounted indicator	CSL
FTx008	Flow Transmitter	ABB	Electromagnetic	90501 002	0062	300	proprietary	16	ambient	0	240 m3/hr	Y	Y	AB Magmaster inline meter with panel mounted display	CSL
LC009	MH 55A (PS3) Level Controller	Milltronics	Ultrasonic	90501 002		n/a	proprietary	atmos	ambient	0	5000 mm	Y	Y	Milltronics Multiranger with 2 sensors in sump, panel mounted indicator. Some alarms from PLC	CSL
PI010	Pressure Indicator	TBA	Bourdon	90501 002	0066	tbc	SS enclosure	5	ambient	0	2 bar	N	N	Standard 50/75/100 mm pressure gauge	CSL
PTx011	Pressure Transmitter	GEMS	Transducer	90501 002	0066	n/a	316 ss	6	ambient	0	2 bar	Y	Y	Pressure transmitter and panel mounted indicator	CSL
FTx012	Flow Transmitter	ABB	Electromagnetic	90501 002	0066	300	proprietary	16	ambient	0	540 m3/hr	Y	Y	AB Magmaster inline meter with panel mounted display	CSL

6. Functional Design Specifications (FDS)

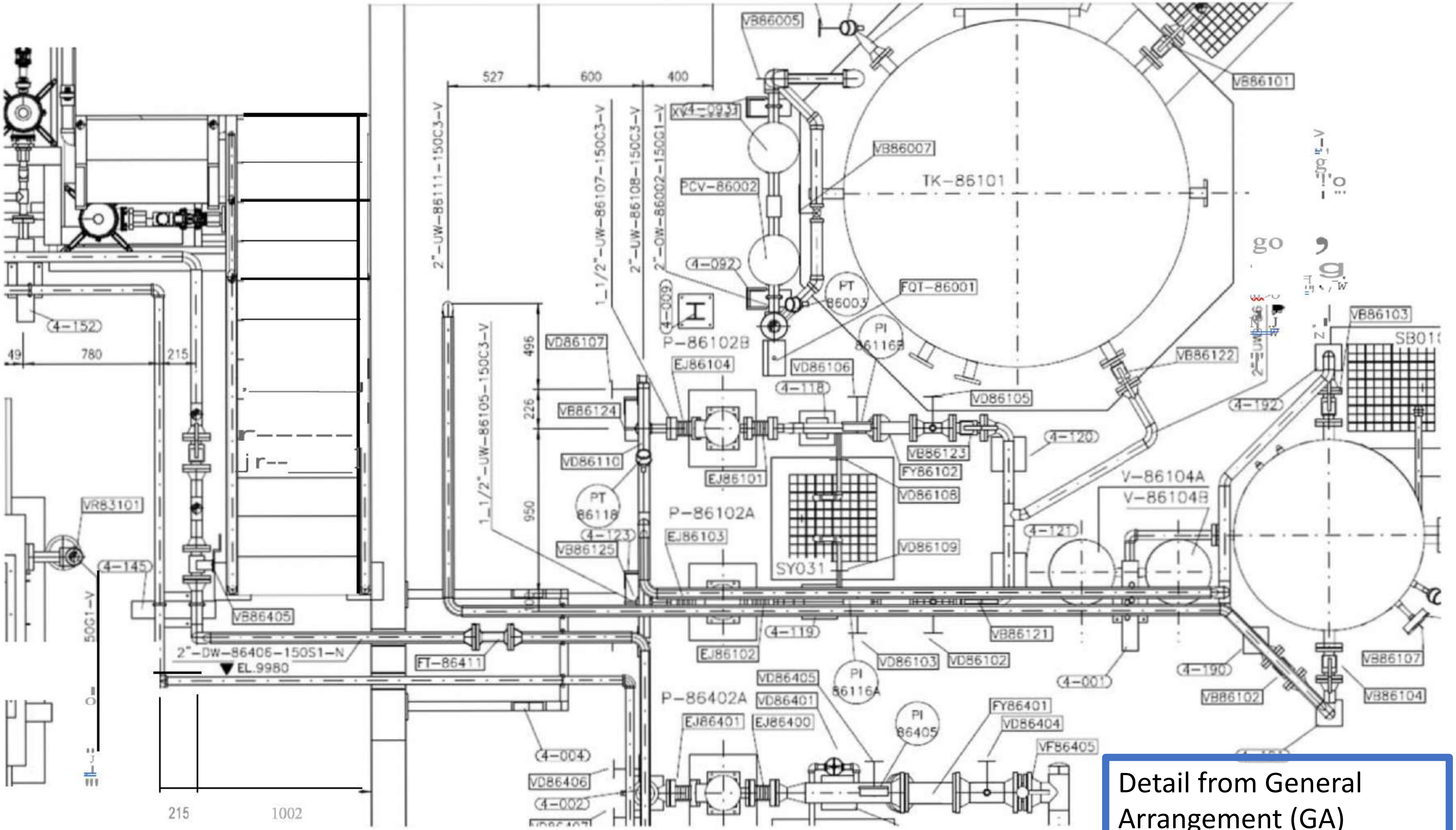
- The functional design specification (FDS) document is developed to describe what the process engineer wants the control system to do.
- It starts with an overview of the purpose of the plant and proceeds to document, one control loop at a time, how the system should respond to various instrument states, including failure states. This description will be set out in clear and straightforward language, designed to be entirely comprehensible by non-specialists.
- The FDS is read in conjunction with the P&ID and refers to P&ID components by tag number. It is used alongside the P&ID in HAZOP studies but is not usually used directly by the layout designer, although the choice of control approach does have layout implications, as discussed later.

7. General Arrangement Drawings (GA)

- Plant, equipment, and pipework layout drawings of various kinds are the primary tools of the layout designer.
- A single GA drawing can show a small process plant, or even a whole site, including sufficient details of pipework to allow its design and installation to be carried out (or, in the case of an "as-built" GA, how it was installed).
- Piping layouts are usually drawn at a 1:30 (sometimes 1:50) scale, and plot plans are usually drawn at approximately a 1:500 to 1:1000 scale. Plot plan scales are far too small to show piping with any meaningful clarity for large plants.

(Cont'd.) General Arrangement Drawings (GA)

- In professional practice, a specialist piping or mechanical engineer may produce the finished piping layout and plot plan, but chemical engineers always lay out equipment in space, and may produce a single GA for small plants or multiple plot plan drawings for large ones as part of their design process.
- In the UK, GA drawings should conform to BS 5070 and, in the US, to ANSI/ASME Y14.1 "Engineering Drawing Practice." They should show (as a minimum), to scale, a plan and elevation of all mechanical equipment, pipework, and valves which form part of the design, laid out in space as intended by the designer. Where possible, the tag numbers used in the P&ID should be marked on to their corresponding items on the GA as well, to allow cross-referencing, as illustrated in next slide.



Detail from General Arrangement (GA)

(Cont’d.) General Arrangement Drawings (GA)

- The inclusion of key electrical and civil engineering details is normal in professional versions.
- Ideally the drawing will be produced to a scale (1:100 being the commonest scale for single GA small plants). Sectional views demonstrating important design features are a desirable optional extra in 2D drawings.
- There are two issues of 2D layout plans at each stage of the design process: the first are “issued for comment” and can be amended by members of the design teams. At the final “issue for design,” the layout is frozen and financial sanction and planning permission will be sought.

8. Cost Estimate

- Equipment prices for specific items will be obtained from multiple sources. The specifications of these items will in turn come from a design which is sufficiently detailed to obtain an appropriate degree of certainty/control of risk.
- Civil, electrical, and mechanical equipment suppliers and installation EPC companies will also often be invited to tender for their part of the contract, although internal design and cost estimation resources may be used, especially early in the design process.
- Internal quotations are also usually obtained from discipline heads within the company for the internal costs of project management, commissioning, and detailed design.

(Cont'd.) Cost Estimate

- Once there are prices for all parts and labor, residual risks are priced in. The insurances, process guarantees, defect liability periods, overheads, profit markup, and so on are then added. This exercise can take a team of people weeks or months to complete, and the product is a +/- 1-5% cost estimate.
- The input of layout designers to this costing exercise is the production of the GA drawings essential to good civil, electrical, and mechanical design and pricing. Layout designers, however, need to consider cost implications of each decision, although a key aspect of design expertise is not having to check back with cost estimators about which option is the cheaper.

9. Datasheets

- Datasheets present all pertinent information for an item of equipment in a single document, mainly so that nontechnical staff can purchase the correct items (see next slide). Process operating conditions, materials of construction, duty points, and so on are brought together into this document to explain to a vendor what is required.
- Datasheets need to be cross-checked with a number of drawings, calculations, and schedules, and care has to be taken to ensure that they are in accordance with the latest revisions. This is a more skilled task than the generation of schedules, and will therefore be likely to remain in the purview of young engineers for years to come.
- Datasheets are not key documents for most layout designers, but their production requires the completion of layout design to a specified level.

Example of an equipment datasheet

Equipment Schedule and Pricing

Supplier

Client		Prepared by		STM	Date	Nov-03	
Site		Checked by			Date		
Project	Example	Contract ref		C2265	C2295	Rev	0
Section	Skid mounted pumps	Section	X	of	Y		
Compressor						Item	P16,P17

One air compressor, pressurised air storage reservoir and associated controls and ancillaries to provide air for oil water separator (if required) continuous sand filter (if required), DAF unit (if required), air actuated valves, and instruments. Current duty is estimated from preliminary calculations. Suppliers should satisfy themselves that the duty specified is correct and make any adjustments as necessary to the sizing. Supply should be for complete, free standing unit. Dryer to be provided if supplier considers this to be beneficial. System will be located inside control building

Any information not requested which the supplier believes will add to his offer to be provided on separate sheets

Performance parameter	Description	Pipework	Valves	Option1	Option 2	Option 3	Option 4	REV
Min flow (Nm3/hr)				30	10	10	10	
Max flow (Nm3/hr)				90	20	25	35	
Pressure (bar)				8	8	8	8	
Compressor								
Manufacturer								
Model								
Type								
Materials of construction								
Noise levels (dBA)								
Length (mm)								
Width (mm)								
Height (mm)								
Weight (kg)								
Inlet connection (mm dia)								
Outlet connection (mm dia)								
Motor type								
Enclosure class (IEC 34-5)								
Insulation Class (IEC 85)								
Motor Speed (rpm)								
Rated power (kW)								
Efficiency at design duty (%)								
Mains frequency (Hz)	50							
Rated voltage	415							
Rated current (amp)								
Starting (Star delta/DoL)								
Starting current (amp)								
Price for complete system, delivered Manchester								
Delivery period for complete, tested system (weeks)		Target <10 weeks						

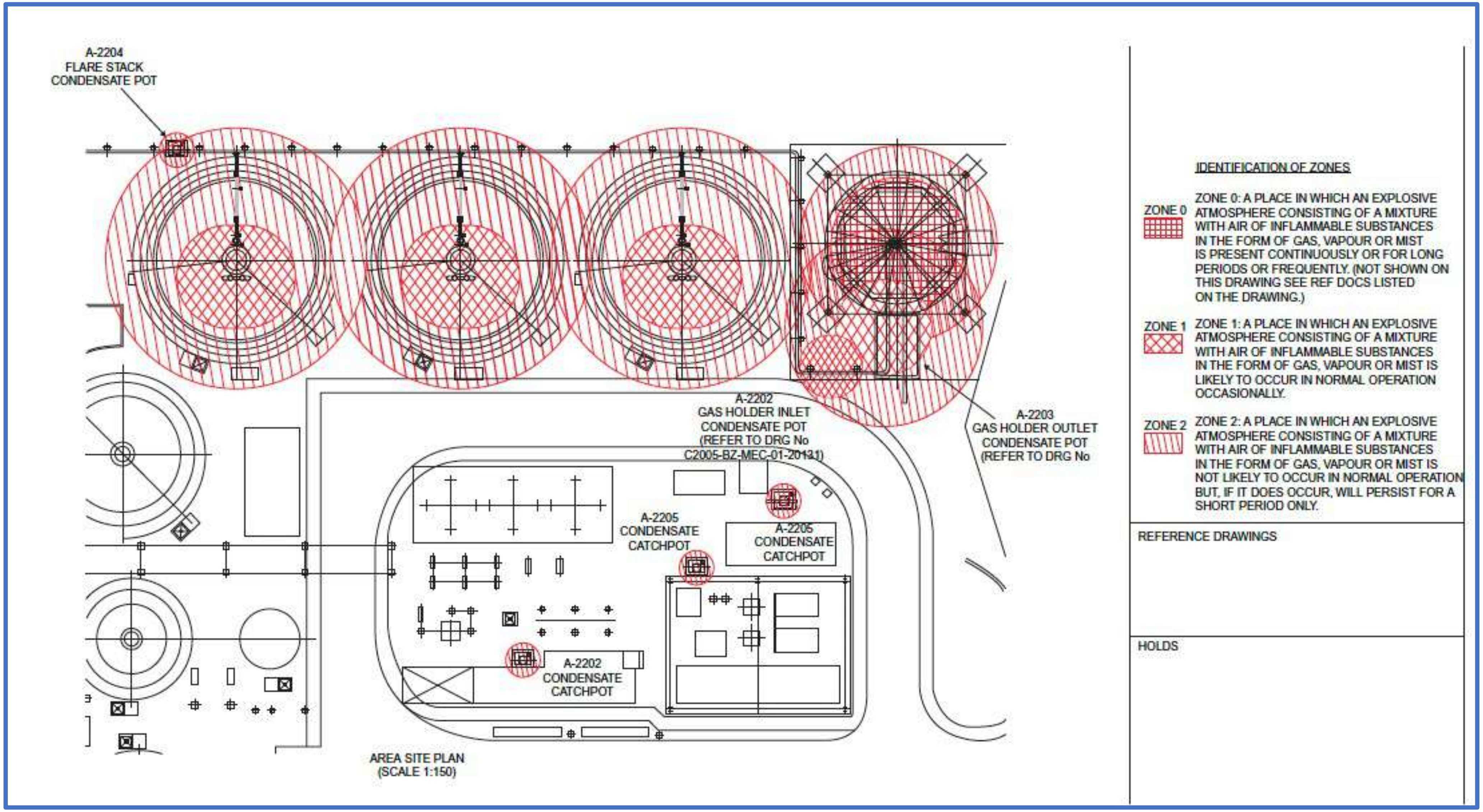
Enter here any additional notes, details of additional equipment or facilities required

10. HAZOP Study

- A HAZOP study is a “what-if” safety study. It requires, as a minimum, a P&ID, FDS, process design calculations, and information on the specification of unit operations as well as around eight professional engineers from a number of disciplines.
- The report produced by the participants will usually include a full description of the line-by-line (or node-by-node) permutation of keywords and properties used in carrying out such a study. However, in the past, it was more usual to produce a summary document listing only those items which were identified by HAZOP as being problematic, what the problems were and how it was intended to avoid them.
- Layout designers are quite possibly not included in the HAZOP team, but HAZOP will disclose the weaknesses of a poor layout. Hazard assessment is therefore a key stage in layout design, covered in more detail in Chapter 8, Hazard Assessment of Plant Layout.

11. Zoning Study/Hazardous Area Classification

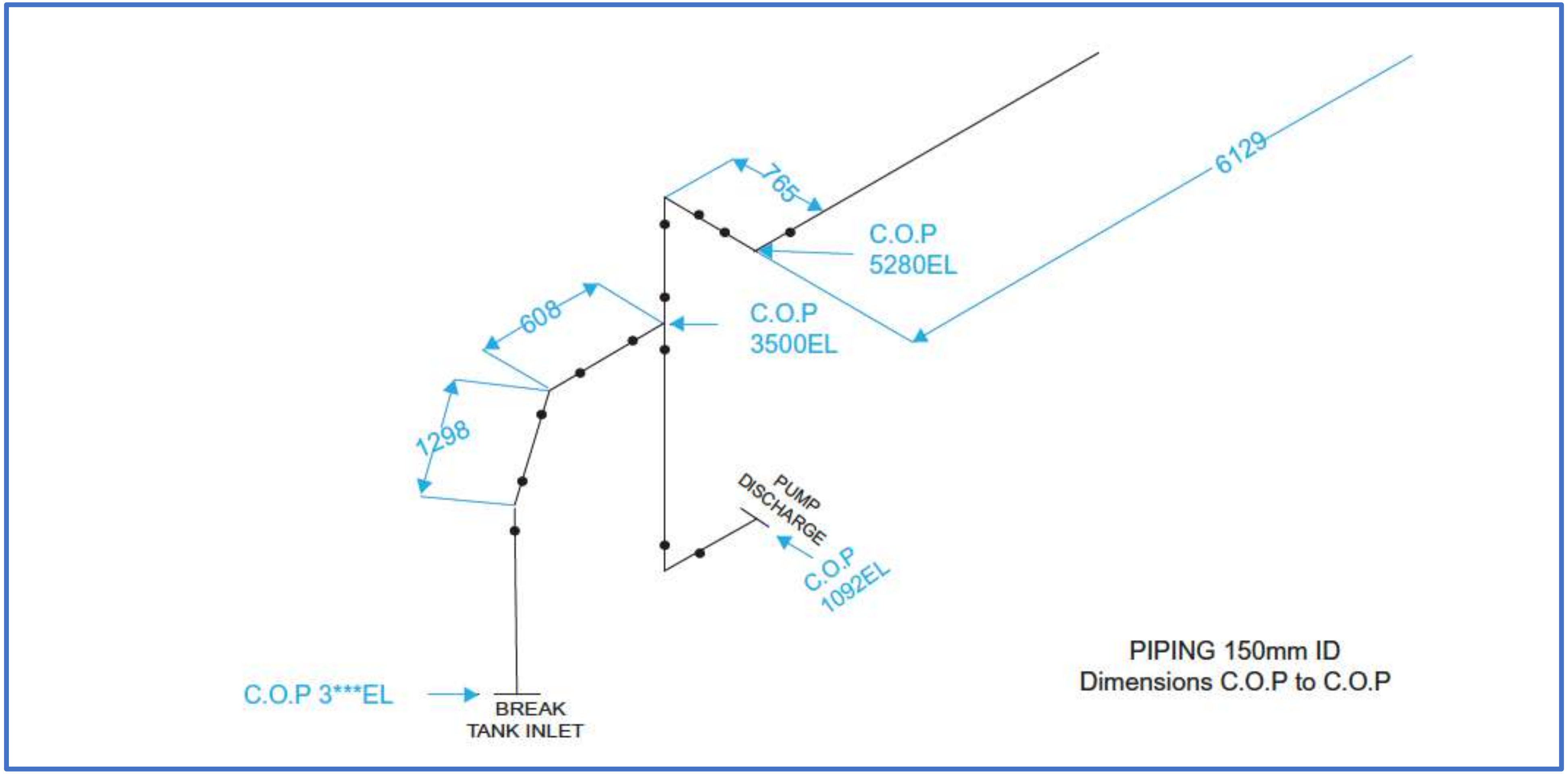
- Zoning the plant with respect to the potential for explosive atmospheres is not a strictly quantitative exercise.
- It is common for a small number of engineers to use design drawings to produce a zoning study (see next slide) or drawings showing the explosive atmosphere zoning which they consider appropriate for the various parts of the plant.
- Zoning can have a major impact on segregation and other issues in layout design. A similar philosophy can be applied to the potential for toxic atmospheres in enclosed spaces.



Zoning study/hazardous area classification

12. Isometric Piping Drawings

- At the detailed design stage, isometric piping drawings, or “isos,” are produced for larger pipework, either by hand on “iso pads” or by CAD (Next slide).
- The purpose of the iso is to facilitate shop fabrication and/or site construction. They are also used for costing exercises and stress analysis, as they conveniently carry all the necessary information on a single drawing. Producing isos by hand or 2D CAD is quite time-consuming. Most 3D CAD plant layout software packages can automatically produce isometric drawings from model databases, but it is still usually thought prudent for these to be checked by experienced pipers, and the setup time of such systems is not worthwhile on smaller plants. 2D CAD is still, therefore, the norm on smaller projects.
- Isometric piping drawings are not scale drawings, so they are dimensioned. They are not realistic: pipes are shown as single lines, and symbols are used to represent pipe fittings, valves, pipe gradients, and welds. The lines, valves, etc.



Example isometric piping drawing

Review Questions

1. The project life cycle has been elaborated in the IChemE Moran Books. Design a table to summarize the 17 steps and highlight the critical steps in your opinion.
2. Present and define the five design stages of a process plant.
3. Design a table to present your understanding of the following concepts:
    a. Standards and specifications
    b. Design manuals
    c. Rules of thumb
    d. Professional judgment
    e. Datasheets