Modularization of chemical plants: An overview

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ABSTRACT

The discussion in this paper outlines modularization approach for standard chemical plants. Each aspect is elaborated in general starting from conceptualization till implementation including transportation. These aspects are applicable to any plant (chemical or industrial) with standard parameters.

INTRODUCTION

Modularization was developed and adopted in the offshore structures to facilitate large volume of fabrication work to be carried out in shop in a controlled environment. Later on, the need was also felt for modular construction of other structure (Onshore) and is fast catching up in many countries, especially developed countries.

This discussion in this paper is limited to modularization approach for standard chemical plants, especially in developing countries like India. In India, modularization approach is not very popular due to availability of large & cheap labour force; high transportation cost due to varied geographical parameters across the country; lesser use of water transport etc. But in coming times, modularization approach will gain wider acceptance.

Stefan Lier[1] and Marcus Grünewald, Ruhr-Universität Bochum of Germany, compared the economics of a modular chemical plant with those of a traditional large-scale plant by investigating investment and operation costs, combined with revenues, using a net present value analysis. They concluded that: "Modular plants consist of modules that autonomously operate parts of the plant. These modules are technically and organizationally limited areas of the plant that fulfill defined tasks." Starting with these modules, companies can create capacity either by equaling up modules from general structures or by numbering up equipment. In the analysis carried out by them, the economics of a modular chemical plant are compared with those of a traditional large-scale plant by investigating the net present value. The modular plant presents a more efficient concept for fast growing products or products with volatile demands. This is because the market impact during operation is more important than the preceding influence of the investment. In those cases, the effects of flexibility surpass the effects of scale.

The conventional approach is *in situ* construction of facilities involved in any chemical plant, using locally available construction men & materials. When such *in situ* construction is not feasible for any reason, modularization can be adopted to reduce the *in situ* work. This can be achieved by using pre-fabricated and pre-assembled modules at locations away from the site. Such pre-fabricated and pre-assembled modules are then transported either by road or ship depending upon the logistics requirements and erected at site.

Modules are generally a set of pre-assembled equipments and ancillaries such as piping, cable trays, cables, insulation etc. Modules may vary in size depending on design, installation, interfacing and transportation constraints.

Modularization facilitates re-usability, as module can be developed, tested, modified and reused multiple times reducing re-development time. Also, the modularized plant can be relocated from one location to another by dismantling.

Key factors influencing modularization

Modularization can be achieved by taking a "stick-build" design and divide into number of modules. Modularization is dependent on a detailed assessment of the key project parameters to determine the feasibility and the extent of modularization.

The key factors[3] are generally labour, site conditions, site access, schedule and safety. Refer Table 1 for key factors influencing modularization.

It may not be possible to go for full modularization every time. Sometimes part modularization may be desirable considering the project parameters and in some cases it may be possible to go for full modularization. At times it may not be advisable to opt for modularization. However, total modularization cannot eliminate *in situ* construction activities such as site preparation, site enabling works, excavation, all civil works including foundations, erection of large fabricated steel vessels and final interfacing of the modules themselves.

The key factor in modularization is the module size that can be fabricated, shipped, transported and erected at site. The maximum size and weight will vary from project to project, depending on the geographical features, availability of equipments for erection and dimensional & weight limitations of the transportation routes.

Modules shall be generally fabricated at locations where labour rates and productivity skill index are suitable as compared to main construction site. However, higher level of modularization will not necessarily translate into cost savings as these will be offset to some extent against the cost of additional steelwork, shipping and specialist land transportation.

Implementation

Constructability aspects for modular projects need to be reviewed well in advance as they impact decisions taken during feasibility and conceptual stages considering overall process, operation and maintenance requirements.

Table 1
Key factors influencing modularization

Factor	Influencers
Labour	☛ Shortage of labour at the project site, or in the vicinity due to any reason ☛ Required competencies of available labour force ☛ Labour and productivity rate for site and shops; the productivity rate of skilled labour in shop is higher than field labour by 25-40%.
Site conditions	☛ Impact of climatic conditions, e.g. cyclonic conditions, extreme cold, wind loading, rainfall, sandstorm, snow loads etc. ☛ Constraints on plot size and area ☛ Seismic zones, e.g. high seismic zones will require more ductile structure with great amount of detailing of joints, large member sizes for lateral load resisting members etc.
Site access	☛ Available routes, infrastructure at site
Schedule	☛ Constraints or requirements of the project schedule, which necessitate the implementation of modular approach or the schedule benefit that would be achieved using modular approach.
Safety	☛ Stringent safety requirements of conventional construction compared to modularization work.

Modularization decisions or changes made during later stages of project can result in considerable rework and may increase overall cost & time to a great extent. A key consideration is the overall plant layout or plot plan, which should be designed to meet the extent of modularization considering all the points mentioned in Table 1. Also the interfacing between modules, erection sequencing, operation and maintenance requirements shall play an important role in making these decisions.

Modular design also facilitates parallel activities, i.e. several modules can be fabricated & built in parallel and can get assembled with higher speed. This helps in maintaining a smaller team at site; overall reduction in time and manpower cost. It can reduce WIP and associated financial costs.

Modularization can be classified in three categories.

- ☛ First generation[2] modularization such as pipe racks, platforms etc.;
- ☛ Second generation[2] modularization such as "customizing" equipment and other ancillaries mounted on structural steel skids; and
- ☛ Third generation[2] modularization such as "standardizing" and not customizing of the modules mounted with equipments and ancillaries.

Considering strength and professional experience of any engineering consultant in India, it is feasible to go for first and second generation modularization as it involves primarily customization, i.e. detail engineering based on the available equipment and schematic plant layout either provided by technology supplier or by customer.

For third generation modularization, it is necessary to have own, patented process technology or expertise of process licensor or technology supplier capabilities of providing technologies for standardization of plant modules depending upon various capacities and volume. However, engineering consultant may collaborate on long-term basis with technology supplier to acquire required expertise, if he doesn't possess one.

First- and second-generation modularization

The following inputs will be required to carry out detail engineering of various modules to be provided. These inputs may help during conceptualization as well.

- The geographical details of site location, seismic zones, wind/cyclone/hurricane factor, soil bearing capacity, groundwater table, soil resistivity, prevalent wind direction and basic wind speed, rainfall, temperature, humidity, snow loads, etc.
- Layout of the proposed plant
- Technological structure general arrangement layouts showing tentative location of equipments.
- P & IDs for process and utilities.
- Customer's design standards.
- Hazardous area classification.
- Data on industrial waste and wastewater treatment etc.
- Customer's philosophy on sourcing spares.
- Details on the new electric power distribution system, viz. system voltage levels, loads, standby power supply etc.
- Master schedule for implementation of the plant, with scheduled deliveries for directly sourced plant and equipment.
- Drawings, data sheets and foundation details for the equipment being sourced directly by customer.
- Module sizes intended depending upon the transportation, constructability, operation and maintenance requirements.
- Procedures for letter of intent, terms of payment, letter of credit, liquidated damages, guarantees, efficiency demands, defects liability period etc.
- Knowledge of shipping and inland transportation constraints such as maximum dimension of shipping consignment, maximum weight for the individual module, etc.
- Preliminary 3D model of the technology structure showing major equipments & piping, if available.

Conceptualisation

The conceptualisation stage is considered to be very significant in any plant design. The key elements of conceptualization are Process Optimization and Energy Optimization.

The following factors largely affect modular design:

- Process engineering;
- Equipment selection;
- Equipment layout and elevations;
- Piping and instrumentation;
- Size of modules;
- Interfacing of modules at site; and
- Availability of cranes in and around the site.

Modularization has an influence on equipment selection and configuration for designing a compact plant layout. Modular designs normally have an optimized footprint compared to conventionally erected plants. The majority of the process equipments can be modularized and located in such a way to lower capital costs and thereby improving plant efficiency. Modular design takes advantage of both horizontal and vertical layouts to locate equipment in a minimum space. A well-designed module can help to minimize space requirements, reduce piping and cable lengths.

Process engineer shall be brought on board during conceptualization stage to extract maximum cost benefits out of modularization. The strategic decisions taken during conceptual stage on overall equipment layout, equipment configuration, piping layouts etc. may prove critical at later date.

Engineers or designers involved should possess multi-disciplinary capability to provide a design that envelopes domain expertise in process, structural, mechanical, piping, instrumentation & electrical design, procurement etc.

Process engineering

Process engineer shall have thorough knowledge of process involved, equipment layout, type of equipments that are required and available in market, various process alternatives, etc. Sometimes it is recommended to design & purchase smaller components of equipments to facilitate modular design, instead of designing equipment that will not fit in the pre-defined module.

Optimizing key process stages during the design phase leads to improvements in plant operation and thereby improve operating and maintenance cost. Process equipment may be more efficiently utilized by applying proprietary designs, converting batch operations to continuous and reducing residence times from hours to minutes, depending upon the requirements.

Process dynamics and control strategies can be optimized by carefully matching the operating ranges of instrumentation and hydraulics to the equipment.

Energy optimization

Modular systems are best suited for energy optimization because of the closed circuit of the process. Process loop or circuit lengths are shorter in modules, which increases the overall efficiency of the plant due to elimination of the long lengths of piping. Shorter lengths of piping helps in minimizing heat loss and condensation in the pipelines.

In the current industrial scenario of alternative fuels, a properly designed modular system using innovative process techniques can reduce CAPEX & OPEX, thereby reducing utility loads through process & energy optimization.

Civil & Structural engineering

The design of modular fabrication shall have following Civil and Structural design requirements:

Size limitation of the module

- Each module shall be sized, based on the maximum transportable length, breadth and height in consultation with process collaborator or technology supplier.
- Planning of each module shall cater, as far as possible, for self-containment of equipment and associated piping works.
- Cutting section plane for the modules.

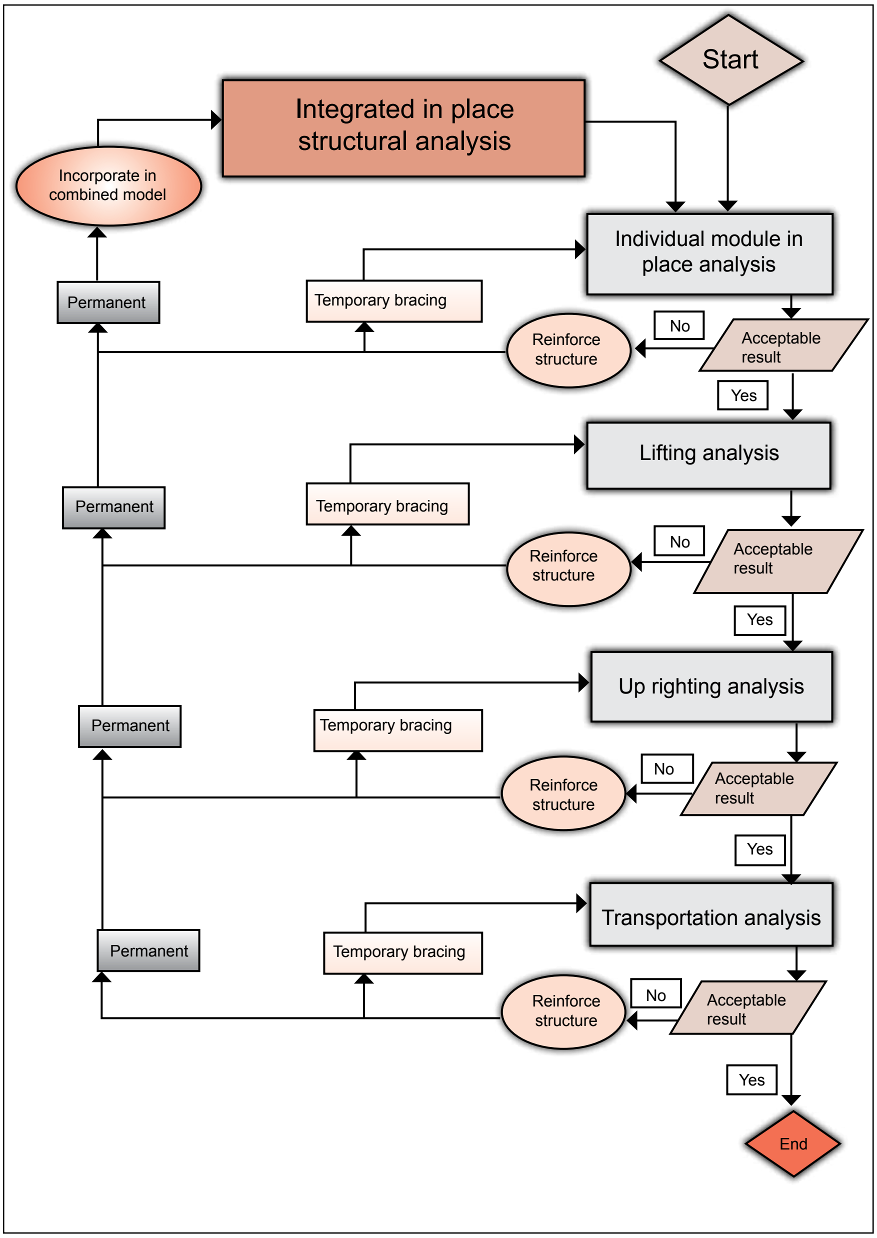

Fig. 1: Typical flow chart of modular design

- The module size shall be selected as a self-standing structure for avoiding imbalance during shipment.

Analysis of the modules

- The entire structure as a single module will be analyzed with "PIN" connection at module interface. This analysis is intended to arrive at overall structural integrity once the plant is commissioned.
- The plant is sub-divided in to various modules as explained earlier. Each module will be analysed as independent structure during erection. The erection scheme needs to be discussed with the contractor or can be decided by engineering consultant.
- The modules during shipment and transportation may have to be arranged in a manner different than its intended position. Such changes require separate set of analysis. A typical flow chart indicating the different stages that are involved in modular design is given in Figure 1.

Structural design

- The structural members shall be designed to account for the forces acting during handling, lifting and transportation.
- All structures shall be analyzed and qualified for such loads other than the normal design loads like equipment load, seismic load, normal wind load etc.
- Additional strengthening may be provided to resist critical forces or to avoid any deformity during transportation
- Identifying the module sections and lifting points.
- Structure to be stable and safe in assembled module as well as in the final constructed form.
- All site joints to be designed as bolted joints and all shop joints shall be welded joints.

☛ Permanent or temporary reinforcement techniques shall be adopted for members likely to be overstressed during lifting and transportation. Connections shall be designed for maximum capacity of the member and checked for stresses arising during lifting and transportation analysis.

Material of construction

☛ Rolled steel members, Wide/parallel flange sections and plates from approved Indian or foreign suppliers shall be used as structural members.

☛ Special corrosion protection allowance or paints to be used to take care of transport and handling.

Additional loading during handling

☛ Tensile and compressive stresses arising from lifting & transportation analysis of the modules.

☛ Rolling, pitching, "heave & yaw" effects of the ship on modules.

☛ Adequate packing or temporary supports (wooden/steel bracings/lacings, shock absorbing materials, etc.) need to provided for the equipments and other ancillaries mounted on modules during transportation.

☛ Generally for lifting and transportation analysis, API RP-2A & GL Noble Denton guidelines may be followed.

Checks required prior to shipment

☛ Completeness of the end connections, checking/testing of weld connections & materials.

☛ Completion of painting and touch up painting before release of the modules for shipment.

☛ Additional temporary bracing members to cater to stresses arising from transportation as well as "Set Down" and "Load out Beam" analysis.

☛ Completion of the tag numbers to all the modules, spare connecting members and match marking.

☛ Demonstrate rigidity of the module by lifting it to a small height duly slung to the lifting hook.

☛ Prior to shipment, check marking of centre of gravity (COG) on modules for lifting operations.

☛ Weight control report shall be prepared before despatch of modules to site.

Civil and structural works required at site

☛ Foundations.

☛ Installation of the modules as per the erection sequencing procedure.

☛ Grouting.

☛ Interconnection of the modules with prefabricated structural members either by bolting or welding.

☛ Installation of the prefabricated operating platforms after erection of stand-alone equipment.

☛ Installation of prefabricated pipe supports, minor equipment structures outside of the module.

☛ Touch up painting.

☛ Encasement and/or fire-proof concreting.

Mechanical design

Mechanical designs shall follow the relevant standards, codes of practices such as ASTM, ASME, TEMA, API, IBR and BIS etc. Flexibility shall be one of the key components of mechanical design. Bolted joints shall be preferred over welded joints. Interfacing for the pipes between two modules shall be with spool pipe.

Sizing of equipment, pipelines for process & utility and selection & location of valves & instruments shall be a part of detailed engineering as per the Project/Plant Design Manual, P & IDs, Data Sheets and relevant codes and standards. Equipment layout shall feature adequate space for O & M, aesthetics and ergonomics, headroom clearances and adherence to the local/international safety norms such as OSHA.

Preferably all the equipment, components, instruments, valves, pipes, gaskets, fasteners, special tools, consumable and capital spares etc., should be sourced from indigenous reputed and ISO certified manufacturers/sources. Provision for easy and fast mounting of imported items, if any, with minimal deployment of men & machinery shall feature in the module.

Process pumps that are to be positioned on the modules shall be aligned with suction and delivery pipes connected. Pumps that are to be installed outside the modules shall be shipped separately with the pump and its drive aligned but short of dowel pins. This arrangement shall also be applicable to other rotary equipment.

Access, i.e. walkway/inter-connecting platforms, to the tall towers such as reactors, stacks, refiners, distillers, strippers etc., shall be featured from related modules.

On the fabricated module, positioning of the equipment shall be completed first. Placement of pipelines shall be after alignment of majority of the equipment. Prior to erection of the fabricated pipes onto the modules, the inside surfaces shall undergo thorough mechanical cleaning using a combination of sponge balls and compressed air or other acceptable practices. Where flange joints are involved, such joints should be at the interface of the modules or with flanged pipe spool.

Welded pipe joints requiring stress relieving shall be completed to the maximum extent on the modules. Metal ring type flanged joints may be used for high pressure lines at the point of separating out from the module to eliminate onsite weld joints with stress relieving. Pipe isometrics running outside the modules shall be fabricated in single or multiple loops and housed in corresponding modules for shipment.

Each module shall be identified with a distinct number. Pipeline designation number and tag number for equipment, valves, instruments etc. shall be prefixed with the module identification number. Tags, punch marks or permanent inscriptions shall be used for identification. Match marks are preferred for pipe loops for onsite assembly.

Equipment, pipes and valves requiring thermal insulation shall be wrapped in the approved insulation material with aluminium sheet cladding. Configured spare insulation shall be supplied loose for onsite fixing at interface of the modules. Fireproofing, also, shall be provided where applicable.

Instrumentation design

All the control room mounted equipment such as DCS/PLC/SCADA system packages shall be sourced either locally or abroad as these require vendor's assistance for enabling, commissioning and fine tuning as per process requirements. As part of the module, the following shall be housed:

- Field instruments, control valves, junction boxes and power supply distribution boards.
- Cabling between the field instruments, junction boxes and power distribution boards, which are contained within the module.
- Cable trays and conduits for the cabling within the module.
- All impulse tubing, fittings supports required for transmitters.
- Local control panel, pneumatic control panels and hydraulic power pack required for equipment contained within the modules.

The multi-core cables and cable trays from junction boxes to DCS/PLC system in the control room shall be laid at site. Analyzer shelter along with analyzer panels & sample conditioning panels installed in it shall be transported as one module. The sampling lines and cabling for same shall be carried out at site.

Instrumentation and control system design and documentation shall be carried out by using internationally proven software such as "INTOOLS".

I&C system design shall follow the relevant code, standards and practices such as NFPA, UL/CSA, IEC, EN and ISA.

Electrical design

Electrical design shall comply with the relevant codes, standards and practices such as NFPA, ANSI/IEEE, UL/CSA, IEC and EN.

Modules shall house the local power distribution board, control consoles, fire alarm panel etc. Cable carrier system consisting of cable trays, tray supports shall be included along with the pipe rack. The module shall include poles, towers, & other supports for mounting of lighting fixtures complete with wiring. However, the fixtures will be fitted on site. The protection enclosure within the modules shall be specified and provided as per hazardous area classification for that module.

For cables emanating & terminating within the module, cable pulling and

termination will be executed as a part of the module. Cable pulling for the cables joining one module to another will be carried out on site.

The main earth strip will be installed on the cable tray and individual equipment earth leads will be welded to this main earth strip. All connections to earth pits/earth electrodes will have to be done at site.

The lightening protection for building/structure/vessels, if required, shall be done at site.

Safety aspects

Safety standards and codes as applicable to the industry and as required by the concerned local authorities shall be adhered to while designing the plant, equipment, layouts and utility services.

The agency(s) appointed for fabrication of the modules shall be required to submit their safety plans for approval, prior to commencement of work. The vendor shall indemnify the purchaser against charges/penalties on the vendor for violation of safety norms resulting in damages to the equipment, machinery, handling apparatus/equipment etc., and/or against injury, accident or death of labour deployed on this job.

Safety norms for electrical equipment shall be in conformity with the rules and regulations stipulated by the competent authorities of the country in which the plant is being installed and operated.

Special design considerations

The plant shall be modeled in 3D environment. The model shall initially show the following:

- Structural steel supporting framework for individual module.
- Lifting points and guying points for the modules.
- Structural steel columns, beams, stairways, walkways/leeways, floor gratings, hand railing, toe plates, monorails etc.
- Plant and equipment.
- Pipelines, valves, and specialties.
- Cable trays.
- Monorails.
- Identify large/over-sized equipment such as columns/reactors/vessels etc., which needs to be transported or shipped and erected separately at the plant site.
- Emphasis shall be to spread the plant and equipment installed on the modules to ensure adequate lee ways, head room clearances, clear passage for movement of personnel and materials handled by the monorails, access for external crane hook, adequate space around the equipments for maintenance etc.
- Layout and spacing of the cable carriers should facilitate safe and easy cable pulls. Light fittings shall be easily accessible for replacement of lamps. Layout of the lights shall be spread to provide desired illumination lumens.

CONCLUSION

Modular design and construction is most suited to almost all plants having standard parameters with less degree of variability. It has brought significant change in the nature of engineering services that are being offered today especially. In India, it may gain acceptance and momentum little slower as compared to the developed countries, due to availability of large labour. To remain competitive in the international market in the future, it is necessary for engineering consultants in India to provide engineering services (in India and abroad) for "Third Generation" modular design by either joint venture or long term association with technology suppliers (international and domestic).

REFERENCES

1. S. Lier. "Net Present Value Analysis of Modular Chemical Production Plants", *Chemical Engineering & Technology*, 05/2011.
2. "IQPC Modular Construction and Fabrication 2013" Conference.
3. "Chemical Plant Design and Construction," Richard Brookfield and Jeremey Cooke.