How feasible are giant, one-train refineries?

The authors . . .

Olson

Hutchinson

H. N. Olson is manager, process engineering, for Fluor Corp. at Los Angeles. His responsibilities include conducting process planning studies and carrying out detailed process designs of various petroleum installations. He holds a B.S. degree in chemical engineering from the University of Wisconsin and is a member of AIChE. K. E. Hutchison is a supervisory process engineer in Fluor's Los Angeles division, concerned principally with process design and plant start-ups. He holds B.S. and M.S. degrees in chemical engineering from Oklahoma State University and is a member of AIChE.

WITHIN the next 8 years, world refiners outside the Soviet bloc will install approximately 25 million b/d of new refining capacity, about one-fifth of which will be in the U.S.

If present practice is followed, much of this new capacity will be in increments of 100,000 to 200,000-b/d grassroots plants and in expansion programs of similar or smaller size. But is this the most economical route?

Would it not be better to build some of this capacity in the form of 400,000 to 500,000-b/d giants? Just what are the disadvantages of such refineries? Does physical size become a limiting factor? How feasible are such huge single-train plants from the operating viewpoint?

These and similar questions prompted an extensive study carried out at Fluor's Los Angeles headquarters earlier this year. The objectives were: (1) Determine if physical size would limit the construction of a 500,000-b/sd single-train refinery, (2) identify operational problems involved, and (3) explore the economics of high-capacity operating units.

Among the task force's more important findings were:

- The 500,000-b/sd refinery is technically feasible and can be designed, constructed, and operated with presently available technology.
- Capital-cost savings in the order of 10% appear possible with the single-train concept, as compared with three parallel trains totaling the same capacity.
- In general, the installed equipment needed for such single-train giants is available or can be built. This may not be the most practical route, however.
- No operating difficulties are foreseen with these huge single-train units when operated at close to rated capacity. But they will be less flexible and more difficult to operate at reduced capacity.
- Disadvantages will include longer start-ups and proportionately larger production losses from shutdowns. The risk of higher production loss from single-train units will have to be weighed against their lower capital investment.
- Only construction limitation is the handling and lifting of heavy loads. Other aspects of building these giants can be accomplished with proper organization and planning.

Basis of study. A 500,000-b/sd single-train refinery was selected for study, with the units sized from the total plant capacity without regard for unit sizes now in existence. The restraints normally encountered in existing plants were ignored to see what concepts might be developed. The study was not intended to solve the problems identified, but rather to spotlight them for evaluation.

An analysis was made as to whether or not a cost advantage existed for the large single-train plant, as compared with one in which on-site units were made up of three parallel trains. Tank-farm requirements took into consideration the changing intermediate storage required by larger processing units. Changes in other assumed off-site requirements also were considered.

Makeup of the hypothetical 500,000-b/sd plant would be as follows:

- Atmospheric crude unit, 500,000 b/sd
- Vacuum unit, 220,000 b/sd
- Delayed coker, 90,000 b/sd
- Fluid cat cracker, 110,000 b/sd
- Naphtha hydrotreater, 160,000 b/sd
- Catalytic reformer, 190,000 b/sd
- Distillate hydrocracker, 90,000 b/sd
- Distillate hydrodesulfurizer, 150,000 b/sd
- Gasoline treater, 70,000 b/sd
- LP-gas treater, 35,000 b/sd
- Alkylation unit, 35,000 b/sd
- Sulfur plant, 750 tons/sd
- Hydrogen plant, 190 MMscfd

In addition to these units, the plans call for saturated and unsaturated gas plants, as indicated in the schematic flow diagram. The cat-reforming and hydrogen capacities would be made up of twin units. Otherwise, all units would be single train.

Site of the grass-roots facility would be either the East Coast or Gulf Coast. Feedstocks and products would be delivered by pipeline, with deepwater terminals within an economic distance. Plant storage will be minimal; 7 days for feed and 12 days of products, with varying intermediate storage between units.

Equipment considerations. The vessels and other equipment for a 500,000-b/sd single-train refinery can reach such dimensions and weights that extensive study and design work become necessary.

The large-diameter fractionating columns for the crude and vacuum units present difficulties from the standpoint of tray supports. In the case of the crude column, which is about a 43-ft-diameter vessel, one solution is to run the vapor line internally down the center of the column to the elevation where the line exits to the condensing system.

This is a radical approach but it has merit. First, by proper design the internal line becomes a support for the tray system. Second, the external piping arrangement and its resulting support problems are eliminated.

Present opinion is that neither the crude nor the vacuum column presents any unsolvable design obstacles. The tray spans in the vacuum tower offer some difficulties, but none so serious that they cannot be overcome.

Reactors for the hydrocracker and other hydroprocessing units present no problem, except for a weight restraint of about 2,000 tons. This limitation is set by the handling and erection capabilities of today's construction equipment. Technology for designing and fabricating high-pressure reactors is available, both for shop and field construction.

Single-train heavy-wall fractionating columns, such as a stabilizer or depropanizer, could require field fabrication. Thus the additional cost of in-place fabrication will have to be taken into consideration in deciding whether large, single-train or smaller, multiple-train vessels are to be used.

Another factor to consider is that the field-fabricated vessel would have to be hydrotested on site. The overall costs of field-fabricating the single vessel thus may exceed those of shop fabricating two smaller vessels.

Compressors and drivers. Sufficiently large compressors are available for these giant single-train plants, with the possible exception of the air blower in the FCC unit. A 100% capacity (400,000 cfm) unit is technically feasible from a design viewpoint. The two 50% units (200,000 cfm) the operator might prefer, in order to reduce the risk factor, are in the same size range as blowers now in operation.

Drivers also can be obtained in the desired sizes. Large steam turbines of the required horsepower are offered and electric motors of 80,000 bhp are currently in aquaduct service. Gas turbines with ratings as high as 55,000 bhp are available for generator drives; there are indications that 100,000-bhp units may be built in the near future. Extensive marine experience with large speed-increasing gears assures they will be readily available.

Use of power-recovery expanders also was considered for these giant plants. Indications are that expanders will have greater use, as a means of improving plant economics, than in today's multiunit refineries.

In-plant power generation could be attractive. A large amount of interruption-free power will be important to the on-stream factor of giant plants. This factor alone could dictate in-plant power generation.

Heat exchangers. A number of problems arise when scaling-up heat-exchange equipment to handle a plant of this size. However, in most applications the solution will be an increase in tube length and shell diameter to something greater than normally found in today's plants. Where large duties are handled by air coolers plus large shell-and-tube trim coolers, physical space requirements become very important in establishing the amount of air cooling that is to be carried out.

Another obstacle area might be the high-pressure exchangers used in hydrocrackers. Here, there may be no choice but to increase the number of shells, rather than use larger diameters. In many cases we already are using diameters at or near the maximum most vendors can fabricate. The problem can be overcome but equipment costs will tend to be higher.

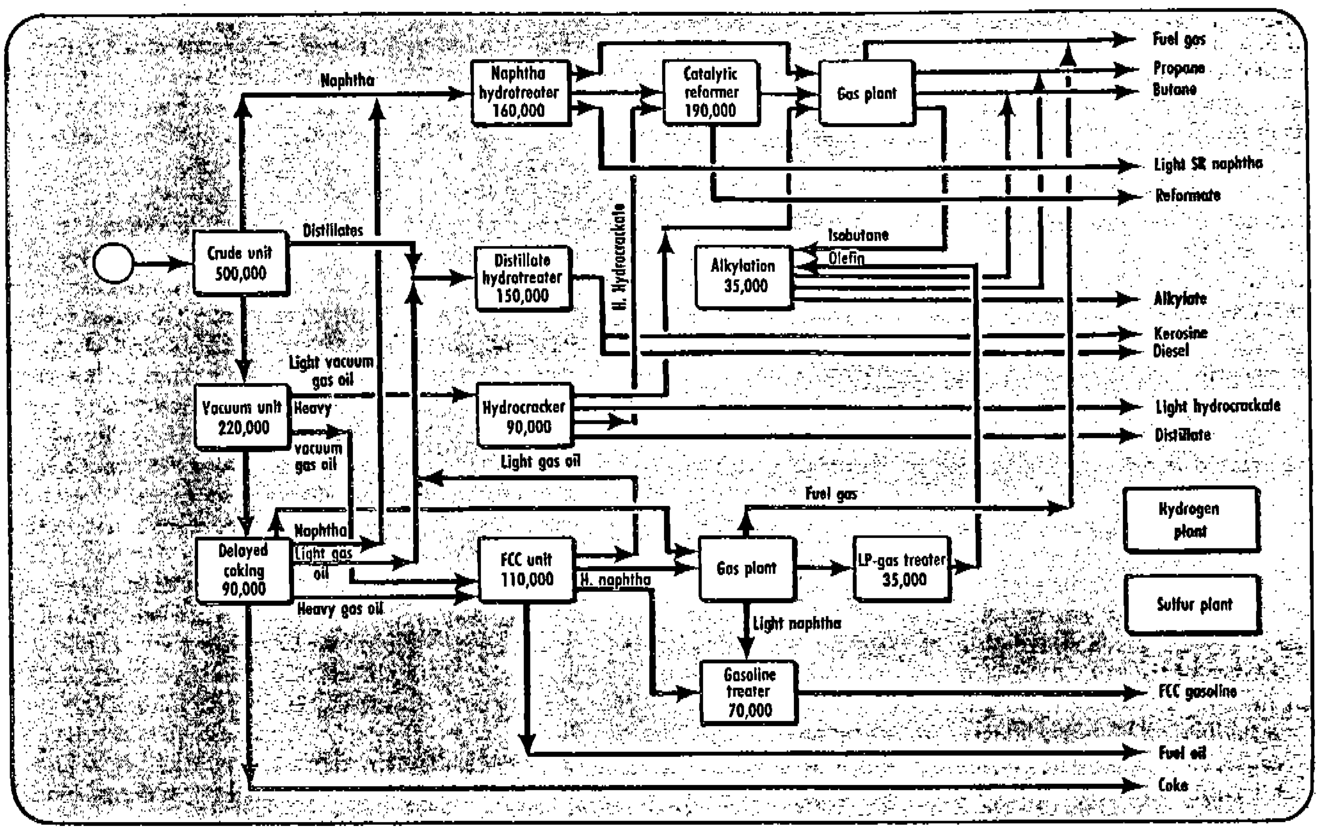
As for costs, the adage that the larger the exchanger, the lower the dollars per square foot holds only up to a point. The curve tends to become rather flat in the 3,000-4,000-sq ft range. The cost per square foot actually goes up again when the unit gets awkward to fabricate and handle in the shop. This varies from shop to shop.

Heaters. Mechanical limitations apparently do not preclude use of one full-size heater for the atmospheric crude unit and one for the vacuum unit. Fabrication and operation possibly would be easier if two parallel atmospheric-unit heaters were built, however. Length of the large outlet collection header would be reduced, and the convection bank tubes would be kept within reasonable lengths.

The application for fired reboiler service on large columns is very straightforward and the extrapolations do not go beyond present heater technology and practice. Designs exist that are much larger than the requirements for this type service. Heater services for hydrotreaters, hydrocrackers, and other units of this type do not appear to be excessive in heat release. Thus no major design problems are anticipated for this class of furnace.

The steam methane-reforming fur-

The 500,000-b/sd refinery



nace does have a limitation in size. Length of the effluent collection header tends to get excessively long as additional parallel passes are added.

Present practice indicates that 90-MMcfd hydrogen plants are about as large as is practical. If capacities in excess of this are desired, they should be met by paralleling the hydrogen plant. Even with plants in the 90-MMcfd size, the reactor or catalyst beds now are paralleled for pressure-drop reasons and diameter economies.

Pumping equipment. One problem with existing pumps is that those built in a size and head capacity to meet the requirements of a large refinery are not designed for hot-oil service. Moreover, NPSH is a limiting factor in large capacity pumps.

The crude-charge pump would be rated at 8,500 gal/min. This size pump is available in the head and capacity requirements, but the NPSH requirement far exceeds available limits.

One solution to this situation would be to use an entirely new design. This could cost as much as $25,000 for each pump, which would be uneconomical unless the cost could be spread over a number of identical pumps. An easier solution would be to use multiple pumps taken from existing designs which meet the operating requirements.

One way to meet the NPSH problem would be adding a second or booster pump ahead of the high-head pump.

One deterrent to the use of multiple pumps in large-diameter lines involves the forces developed from unequal temperatures in a complex header system. These forces complicate the design and layout of the system since they are imposed on the pumps and headers.

Large pumps are a little more efficient than the small standard pumps found in a refinery. However, if the requirements for a 500,000-b/sd crude unit were split up into four parallel pumps, they would still be in the size range in which maximum efficiencies have already been obtained. Thus there is no particular advantage for a single operating pump over two or three parallel pumps. The arrangement with proven pumps would be much more attractive.

Use of power-recovery units becomes more attractive in giant refineries. There are undoubtedly many areas in which it would be economical to recover horsepower from large-flow liquid systems or flashing reactor-effluent systems. The large size of the units would make power recovery more commonplace than it is in present processing units.

Piping and plant layout. In such large refineries, it is evident that the large piping and equipment will have major effects on plant layout. There will be many situations of large inflexible pipe connecting large equipment. Uneven settlement of equipment could aggravate piping problems.

It may be necessary to take a new look at some standard practices used in present-day plant layouts. As an example, the practice of locating pumps under a pipeway becomes impractical when the pump becomes as large as major pieces of equipment.

Supporting systems for pipe become more complex and extensive. A more practical plant layout may result in locating the pipeways at grade, with operator access provided by catwalks and platforms above the piping.

Plant appearance and noise levels will also affect plant layout. Flares will be located so as to minimize this distracting effect on the surrounding areas. Tankage could be located so it will act as a sound barrier and also hide the unsightly parts of the plant. Baffling may be required to provide acceptable sound control. Noise-generating equipment will be located to minimize its effect on outside areas.

The problems of plant layout could be quite extensive. Early client agreement will be required on design criteria, equipment spacing, routing of lines and other design guides as basis for developing a plant layout.

In general, no piping difficulties were encountered which could not be solved. It is possible, however, that an entirely new philosophy on plant layout could evolve from designing a plant this size.

Instrumentation. Amount of instrumentation will not increase at the same rate as the capacity. For instance, the number of control loops would vary as the number of units, not the size of the units. It is expected that the control room for the refinery would be essentially the same size as for a comparable refinery with a much smaller throughput.

Computer control could appear more attractive in the large refinery, especially if supervisory control were included. The size of the computer would be about the same for either a small refinery or a large refinery. Therefore, from the standpoint of capital outlay, it could prove very attractive.

Advantages such as an increase in throughput and a decrease in off-specification product would be realized at about five times the return for the large refinery for the same capital investment.

Some types of process sensors such as pressure transmitters, thermometers, thermocouples, level transmitters, and d/p cells would not change with the size of a plant. These will not present any new obstacles and standard hardware will be suitable for the large refinery.

Control valves will have to handle large flow quantities and may present size problems. As a solution, multiple valves would be used as has been done in some plants designed by Fluor. Maximum use of ball and butterfly valves would be recommended because of their greater capacity for a given size.

Relief valves would present a size problem in both the crude unit and cat cracker. Here, too, it would be possible to parallel a large number of relief valves. An alternate to this is the use of two 100% capacity rupture discs with isolation valves. Another alternate is the use of a combination of rupture discs and relief valves. Minor upsets would be taken care of by relief valves and major upsets by rupture discs.

Flow measurement will not be excessively difficult for large lines within the plant. The standards of the ISA for orifice plates apply to lines up to 24 in. in diameter, but successful extrapolation of data has extended the use of orifice plates to lines of 30-in. diameter and larger.

Since orifice meter runs in large sizes can be exceedingly long, venturi tubes requiring shorter run lengths could be considered as an alternate. The size of the primary flow elements would be larger than we normally provide, but no unusual problems are expected.

Construction. Available equipment is capable of handling and lifting loads up to 2,000 tons, as long as the item being lifted is not excessively high.

Field fabrication of heavy-wall vessels is possible and welding techniques and stress-relieving techniques are available to produce an acceptable field-fabrication job. It should be pointed out, however, that difficulties in connection with the field-fabricated heavy-wall vessels could outweigh any cost savings indicated by selecting the low bidder.

The fabricator's qualifications must be weighed against a low price since poor performance in the field has a direct bearing on the construction schedule. Another factor affecting the amount of vessel field fabrication that can be successfully done is the availability of qualified boilermaker welders.

It is evident from experiences on Fluor's major projects that detail planning and organization tailored specifically to a large project is very necessary. Communication becomes very important as the size of a project increases.

Pollution control. Pollution control should be no more of a problem than for a refinery in existence today. Because of its size, the large refinery could economically use methods of control which would not be practical for a small refinery. It may be economical to reclaim certain chemicals used in treating which would result in a reduction of pollution problems.

Maximum water reuse would be a major objective for this size plant. More extensive use of air cooling will likely be possible. It is very likely that the utility units would be centrally located. This would save piping and provide a fire barrier for the process units.

Operating considerations. The large diameters of some of the vessels required could result in operating problems not encountered in today's plants. Thus various towers and reactors were evaluted from this viewpoint.

Large-diameter fractionating columns were found to offer no operational difficulty if the tray hydraulics were designed on the basis of present practice. The large columns would be expected to have different response characteristics than present-day smaller units. Turn-down ratios likewise might be more limiting.

The delayed-coker-drum diameter will be limited by the ability to hydraulically remove the coke. The present proven operation is with 26-ft-diameter drums. We have concluded that 30-ft drums represent a reasonable extrapolation from proven practice. The coker for our hypothetical refinery would require 10 drums at 30-ft diameter.

Operating stability of a large-size single-train processing unit will be different in characteristic from a more conventionally sized unit. Fractionators will require a much slower response time for heater-firing controls, reflux-temperature controls, and all of the various responses to measurements within the unit. Size of these units will require considerable restraint in responding to operating measurement and signals in order to stay within the control range of the equipment.

The large crude unit will be fairly difficult to operate at 50% capacity due to the inordinately long response times to changes in processing control. If the unit were operated at this capacity for an extended period, it would require considerable retuning of instrumentation to stay within the range of stable operation.

On-stream factors. The unscheduled outage of a process unit or mechanical system follows an average frequency rate based on the number of operating machines whose failure will require shutdown. For the above reason, it is desirable to have as few operating machines in a single-process unit as possible. The incentive is to make the pumps and compressors as large as possible to keep the total number at a minimum.

The analysis of large-size units for all of the processing systems indicates a few situations in which multiple or parallel operating pumps are required. The air blower for the FCC unit may very well be two blowers in a single-train configuration.

If the breakdown frequency is essentially the same for a single-train unit vs multiple-train units, there is no advantage in having multiple units from a frequency of breakdown standpoint. However, this assumes that the time required to repair a breakdown is equal. But since the large size, single-train units will take longer to repair, there is a greater loss anticipated due to suspended production for maintenance, scheduled or unscheduled.

The maintenance downtime will be longer for a large size single-train processing unit because of more massive lines to be disconnected and blinded, larger pumps to be removed and maintained in the shop, and the larger heat-exchanger bundles to be removed.

All of these things will require more people, heavier machinery, and a longer time to make repairs. The actual additional time required for maintenance of larger equipment cannot be specifically stated, rather a directional effect should be noted.

Intermediate tankage for process units is governed by the size of the unit and the anticipated downtime for maintenance and repairs. The intermediate tankage would be much less for two parallel units since only one of the units would be considered for continuity of feedstock to downstream processing facilities. There would also be a slight advantage for the half-size units in that the maintenance time would be less than for the full-size units.

These factors indicate the intermediate tankage requirements would be reduced with smaller process units. However, the additional process units add more cost to the project. Larger-size process units are more difficult and time consuming to bring on stream and reach production capacity. The period of off-spec production is longer and the quantity of off-spec product will be proportionately larger.

Shutdown procedures for large refinery units are longer because of precautions necessary to avoid mechanical damage to equipment and to make units safe for maintenance. The operating production loss for a single-train unit will be greater than the ratio of unit size, due to increased elapsed downtime for maintenance.

If the operator is prepared to absorb losses proportional to the production rate that the operator of 100,000-b/sd refinery would accept, then there is no deterrent to installing the maximum-size process unit. However, if the production losses of a 500,000-b/sd refinery single-train processing unit are in excess of what is tolerable, then the reduction to smaller trains is inevitable.

The reduced operating loss for multiple-train units must be weighed against the increased capital investment.

The return that can be shown on a single-train unit at a lower capital cost, with its intermediate tankage, might be attractive to an operator as a long-term investment, even with the anticipated loss of production from a large unit shutdown. END

NELSON COST INDEXES

Refinery construction (1946 basis)

Explained on Page 97 of the issue of May 15, 1967

	1954	1960	1968	1969	1970	Aug., 1970	July, 1971	Aug., 1971
Pumps, compressors, etc.	166.5	228.3	284.4	298.6	313.1	316.8	331.2	332.8
Electrical machinery	160.0	195.2	198.2	201.7	208.6	209.6	214.6	215.4
Internal-comb. engines	150.5	180.7	198.9	207.4	217.0	216.6	224.3	228.4
Instruments	154.6	202.5	239.1	252.8	278.8	281.7	309.7	309.7
Heat exchangers	171.7	194.0	223.4	235.8	253.8	251.7	270.4	270.4
Misc. equip. average	160.7	200.0	228.8	239.3	254.3	255.3	270.0	271.3
Materials component	174.6	207.6	224.1	234.9	250.5	252.2	266.7	267.9
Labor component	183.3	241.9	357.4	391.8	441.1	456.4	507.6	514.4
Nelson Refinery (Inflation) Index	179.8	228.2	304.1	329.0	364.9	374.7	411.3	415.8
Construction and Design Productivity	1.708	2.211	2.816	3.092	3.092	3.175	3,486	3.524
‡Nelson Construction (True Cost) Index	105.3	103.2	108.0	106.4	118.0	118.0	118.0	118.0

Refinery operating (1956 basis)

Explained on Page 161 of the issue of Apr. 6. 1964

	1954	1960	1968	1969	1970	Aug., 1970	July, 1971	Aug., 1971
Fuel cost	86.5	109.9	103.8	107.1	129.2	134.7	166.7	167.0
Labor cost	90.9	100.3	91.8	91.3	101.8	102.2	106.4	104.2
Wages	88.7	113.0	158.0	171.3	183.1	183.3	196.7	194.2
Productivity	97.1	112.9	173.1	187.6	179.9	179.3	184.8	186.4
Invest., maint., etc.	92.0	116.9	†105.9	†104.3	†115.7	†115.7	†115.7	†115.7
Chemical costs	85.7	114.3	124.3	125.9	127.4	131.1	120.0	121.1
Nelson operating indexes								
Refinery	88.7	108.8	103.5	104.3	113.9	115.3	117.9	117.3
Process units*	88.4	107.2	101.3	102.5	117.6	119.9	133.8	133.2

*Add separate index(es) for chemicals, if any are used. †Revised method which corrects for productivity and refinery complexity. ‡For refineries actually built (increased capacity, increased complexiey). See Quarterly Costimating, July 4, 1966, p. 110.

These indexes are published in the first issue of each month. They are compiled by W. L. Nelson, Technical Editor and petroleum refinery consultant, Tulsa.

Charts of the indexes are published each year in a late January issue. Indexes of selected individual items of equipment and materials are also published on the Costimating page in the first issue of the months of January, April, July, and October.