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CONVERSION AND OPERATION OF FLOATING S ORAGE UNITS – A HINDSIGHT VIEW

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Conversion and Operation of Floating Storage Units—A Hindsight View

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SYNOPSIS

During the last 15 years it has become economical to develop marginal offshore oil fields by utilizing conventional fixed-leg production platforms, by combinations of fixed platform and floating buffer storage or by a floating production storage unit. The particular method used is dictated by the infrastructure of the producing field in question. Since 1969, Shell International Marine Ltd (SIM) has been involved in the conversion of a number of standard tank vessels either to a floating storage unit (FSU) or a floating production storage unit (FPSU). These converted tankers have been operating successfully for nine years, but with hindsight some of the marine aspects of the conversions could have been handled differently to avoid the pitfalls experienced by the project team and latterly by the operators. This paper discusses the experience of the project teams, the operation of the floating units with which SIM has been involved, and the ideas which may be incorporated in the future for floaters used in offshore developments. Project organization, ship selection, conversion, commissioning and operation are also discussed.

Michael Holderness joined the Anglo-Saxon Petroleum Company in 1953 as an Apprentice Engineer under the alternative training scheme. In 1969 he transferred to Shell International Marine after serving as Chief Engineer in the Shell Tanker Fleet. After a short period in Research and Development he moved to the new construction department as Newbuilding Superintendent and supervised the building of VLCCs in the Netherlands and USA. Since 1984 he has been head of the section responsible for projects relating to offshore vessels, conversions and specialist craft, and has recently become Manager, Contracts and New Business, for Shell Seatex.

D. J. van Dijk enrolled into the Nautical College at Den Helder (Netherlands) after completing high school and obtained a 'Master Foreign-going' Certificate. He joined Shell Tankers BV in 1965 and in 1977 was seconded to Brunei Shell Petroleum Company as a pilot at Seria SBM, Lumut LNG terminal and associated offshore oilfield work. He was seconded to Shell Tunirex as an Offshore Installation Manager on the Tazerka FPSU and was actively involved in the conversion and the commissioning of the FPSU. He is now Offshore Installation Manager of the Fulmar FSU.

Kenneth Downham joined Royal Mail Lines as an apprentice electrical engineer in 1952 and then sailed as an electrical engineer officer. In 1972 he joined Shell International Marine as electrical design engineer and has been involved in the construction of all types of vessels built for the Shell Fleet and also in the development of offshore FSUs, FPSUs and dynamically positioned vessels. He is currently a senior electrical and control engineer dealing with all aspects of marine offshore work.

David Carlisle joined Shell Tankers (UK) in 1968 after an apprenticeship and employment within the shipbuilding industry. After seven years involvement with repairs and maintenance of Fleet vessels, he transferred to Shell International Marine in 1975 as a naval architect within the newbuilding division responsible for a number of hull designs and construction projects, as well as small craft and offshore conversions. Since 1985 he has also taken on the role as focal point for development and advice on hull corrosion and protection systems related to SIM's activities.

INTRODUCTION

There are two distinct types of floaters employed in the offshore oil industry: the floating storage unit (FSU), which acts as a buffer storage between the field and the distribution system, and the floating production storage unit (FPSU), upon which production and storage facilities are installed. In the case of the former, the unit is part of the oil field infrastructure and must be fully operational at all times to prevent field shutdown. In the latter case the system is completely independent of platforms and pipelines to shore, offtake being achieved by discharging to trading tankers. This approach to the development of a field instead of more conventional methods, such as a platform connected by pipeline to shore, is dictated by economics and the lack (in most of the marginal oil fields) of an infrastructure of pipelines, storage etc.

Until the late 1970s, however, tankers were used only as fixed storage with no facilities for producing from sub-sea wells in totally independent oil fields. In July of 1977 the first Shell International Marine (SIM) FPSU was commissioned in the Castellon Field based upon the conversion of the 35 000 dwt

FIG. 1: ***Ildefonso Fierro*** **after conversion**

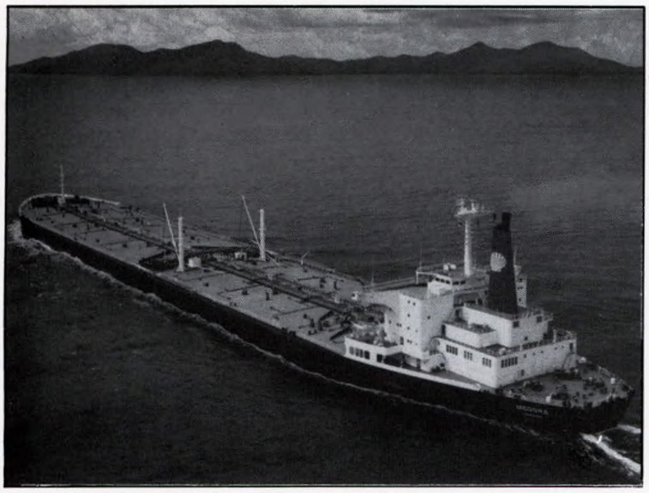

FIG. 2(a): *Medora* before conversion

FIG. 3(a): *Murex* before conversion

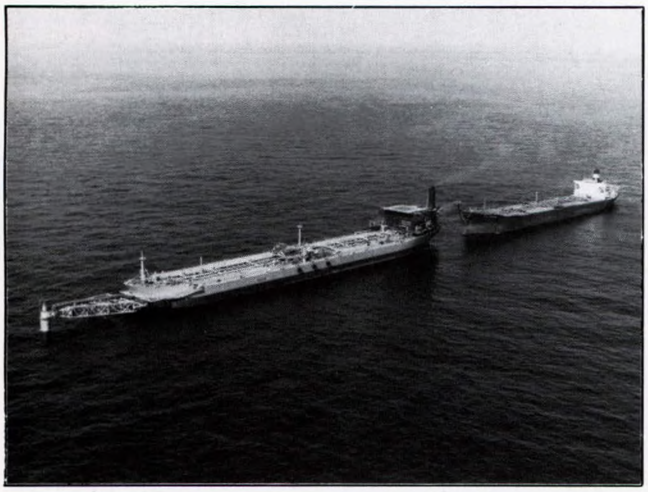

FIG. 2(b): *Medora* after conversion to Fulmar FSU

tanker SS *Ildefonso Fierro* (see Fig. 1). The predicted life was to be four years and the conversion, although relatively simple, was extremely interesting in that facilities were fitted for gas incineration and well workover. The production unit was bought 'off the shelf', being the size normally used for pre-production testing. In the event, this FPSU has lasted almost ten years, but the incinerator has not been necessary and the well workover facility has had limited use.

Following the Castellon Project, in August 1981 *Medora* (see Fig. 2) was converted to an FSU on the Fulmar Field in the North Sea. This vessel of 210 000 dwt was converted to North Sea requirements using many of the vessel's original features and machinery. The similarly sized *Murex* (see Fig. 3) followed in 1982 for use on the Tazerka Field off Tunisia. This was the first fully designated conversion to an FPSU and the design lifespan of this project was eight years. In 1983 the 63 000 dwt *Sitala* was converted for use as an FSU in Gabon.

More recently, SIM has been involved in the conversion of a tanker of 210 000 t for use in the Vega Field off Sicily. This has a projected twenty year lifespan.

PROJECT ORGANIZATION

In each conversion the project was conceived by SIM's exploration and production function (E&P), and vessel procurement, conversion specification development, conversion and site supervision were co-ordinated by SIM. Both E&P and SIM were responsible for evolving their own specification and requirements for the vessel conversion. Thus, from the beginning, the projects drew together different disciplines, with distinctly different standards and practices. Figure 4 shows the organization of the project teams.

FIG. 3(b): *Murex* after conversion to Tazerka FPSU

SPECIFICATIONS FOR VESSEL CONVERSION

SIM's philosophy regarding technical specifications is to be specific but not detailed, giving sufficient substance for the contractor to make his bid but leaving the details to be negotiated and agreed at the pre-contract stage. The final design detail for the vessel conversions were carried out by the contractor, which allowed him to adapt the specification to suit his own work practices and yard capabilities. Contracts were on a fixed-price basis with only a small contingency allowance for post-contract modifications, to eliminate costly 'surprises' during the contract.

Normally in the E&P culture the contractor would be based on a greenfield site. He would have constructional expertise but little design expertise, hence the specification provided would need to be very detailed. The contractor would then bid at a fixed price on a particular module or modules which are closely defined. This type of contract involves supervision on each construction site with considerable pre-contract design expenditure.

The E&P type specification caused difficulties for shipyards, which were unaccustomed to an approach that did not require their design staff, just the shop floor labour and yard facilities. Hence shipyard bids on this type of specification often reflected overheads which were not present at a greenfield site. The shipyard costs were higher than those at the normal offshore contractor since they included shipyard total overheads, irrespective of use.

The difference between SIM's and E&P's approach to the technical bid was resolved during pre-contract negotiations by offering the shipyards the opportunity to participate in the design and construction of modules. This opportunity was seized by the shipyards since it allowed them to enter a market which had hitherto been closed to them.

Thus for a new project a combined SIM/E&P specification was put out for bid and the selected vessel was made available for inspection by the potential contractors. All negotiations were carried out by the combined project team and all equipment interfaces between SIM and E&P were carefuly monitored to ensure:

1. That they were connected in the physical sense, eg the deck landing points were correct for module feet.
2. That when connected the function was correct, eg hazardous drains went to the correct reception area.

SIM has recently completed for non-group customers the formulation of technical specifications for conversion of an existing tanker where the SIM approach has been used to good effect. However, if the floater of the future, or conversion, were to have a lifespan of 10–25 years, the E&P approach of a design study and a design and execute contact should be favoured.

Past experience with the SIM part of conversion projects has been to stay within the fixed price with no budget over-runs. The most likely areas for over-run, especially if budget estimators are not experienced in marine business, has been the normal docking items and more significantly the overhaul or repair of existing equipment if it is to be retained.

PROJECT MANNING

With respect to manpower requirements for newbuildings, SIM has by tradition always been very conservative, spurred by competitive industry where finance has been traditionally restricted. Thus when planning manpower requirements for conversion projects the early SIM concept was based upon the manpower of a team normally used in a shipyard during new ship construction, ie team leader, naval architect and steel/paint inspector, with the team leader doubling as the engineering adviser, and a central office providing expertise in electronics, electrical fittings and instrumentation.

The E&P attitude to a conversion contract has been to provide manpower encompassing specialists from every discipline required for the particular project, supported by planners, store superintendents etc. The E&P attitude, while absolutely valid for the greenfield site, is not necessary for a shipyard nor possibly for non-shipyard conversion. In practice a compromise between both approaches would appear to be the best solution.

Having covered the specification and manning aspects of project organization, it should be mentioned that for optimum results the manpower for the project is housed in one building. If this approach is not followed weakening of team effort will follow.

In a recent SIM project, personnel from London were located in the client's project offices in Italy. This worked well with the core team providing the working expertise and specialist back-up coming from London.

THE CONTRACT

SIM contracts have in the past been extremely concise but also very effective, being based to a great degree upon trust between people in an industry where there were few outsiders in terms of unknown owners or contractors, and companies often had associations with each other which spanned 20 or more years. In the offshore oil industry this was not the case, thus the requirement for a very detailed contract was absolutely essential.

For a conversion contract a combination of the SIM and E&P approach is advisable. A comprehensive contract will provide the project management with sufficient detail to monitor and, if necessary, to penalise the contractor throughout the duration of the contract.

VESSEL SELECTION

Vessel selection is governed by many factors, including field production rate, the frequency of offtakes which operators require, and whether offtake shall be by dedicated tanker or by any trader available. Naturally the geophysical position of the field is also of great importance from a vessel stability aspect, ie a VLCC produces a more stable platform than a smaller vessel. Size of vessel will also have a dramatic effect on the size of the mooring system, which is directly related to the cost of the system.

The most important factor and one which dominates vessel selection is the field life prediction which, in SIM's experience, has in the past been on the low side. For a short field life of say four to five years a vessel costing for example $4 M might be suitable, but if 20 to 25 years life is required the vessel cost could be three times this amount.

In the tanker market of the late 70s and early 80s, many VLCCs were available for conversion, thus the project team, having selected the size of vessel, would go out on to the market via ship brokers. In consequence the market usually became excited, with prices tending to rise.

Initial evaluation should identify perhaps six vessels for preliminary inspection by a project ship inspection team to assess such areas as machinery operability and condition, in-tank steel condition, the availability of deck area and its

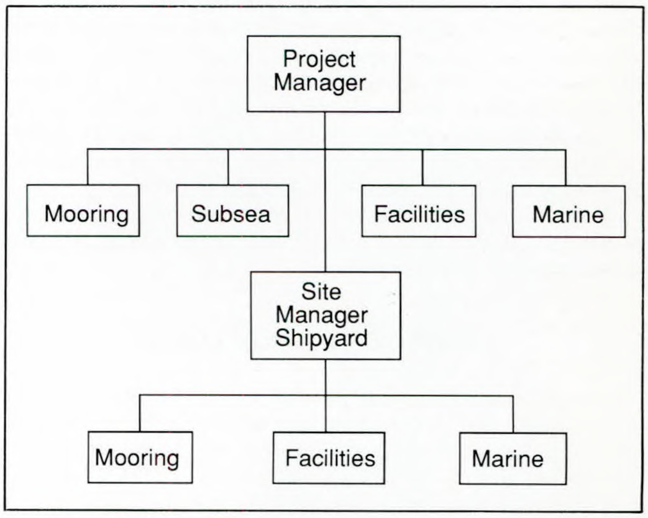

FIG. 4: Organization of project teams

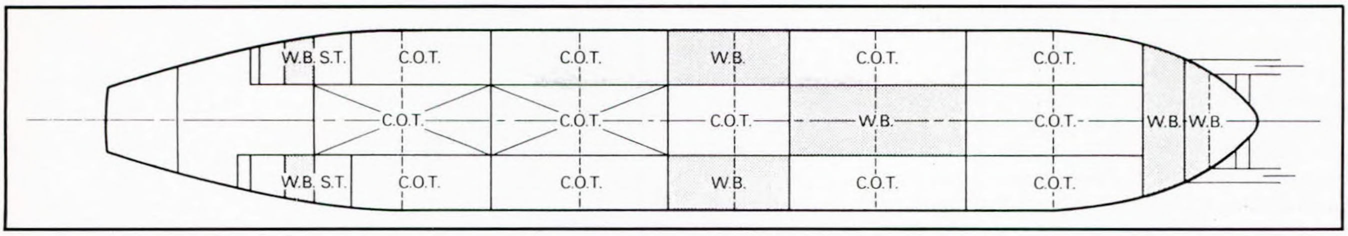

FIG. 5: Tank layout of Fulmar FSU

suitability to fit production units etc. Vessel operational requirements may preclude inspection of many tanks, but if a vessel is high on the list of potential purchase, a decision must be taken in commercial terms whether to inspect completely a vessel's tanks and pipelines or to rely on past records. In SIM's experience it should not be the latter. For example, in one project where records indicated a sound vessel it was agreed to compensate the owner to clean the vessel's tanks for close inspection. The inspection revealed heavy, deep pitting of the tank bottoms throughout the vessel, the repair cost of which would have been many times the cost of the tank cleaning exercise.

An experienced marine inspection team can soon ascertain the condition of a vessel and what must be done to preserve it for many years exposure to a harsh environment without docking. One area, in which even the most experienced marine team can be misled, is cargo and ballast pipelines, where only by removing selected sections can the condition be determined. In SIM's experience mistakes in this area can be very costly if some or all of the cargo piping or ballast piping is to be retained in the converted vessel.

When selecting a vessel a project team must consider its philosophy relating to retention of existing machinery and the type of accommodation required, ie is it just for the FSU/FPSU crew or possibly as a 'flotel' for a field. The team must also consider what requirements will be placed upon the converted vessel by the Classification Society and, probably more important, the country in which the unit will operate, for although Classification rules are normally universal, national requirements often vary dramatically. Secondary to motion characteristics and often fixed by the available choices, vessel shape should be considered when grading the possible choices because a more stable platform will assist the operation of production equipment and the choice of offtake system.

In SIM's experience, the greatest problems, after selection of the vessel, have been in cargo tanks and to some extent the retention of the original ship equipment. The severity of the problem is dependent upon the projected life of the vessel. Should the project's lifespan be 20 years, and if the budget allows, it is better to refurbish selected items, abandoning most of the original equipment and fitting deck-mounted power etc. However, for a short field life, retention and some judicial supplementing with new equipment would be the route recommended by SIM.

Selection of the vessel is rather similar to buying a second-hand car and is fraught with pitfalls if a project team does not have expertise in dealing with ship acquisition, both from a commercial and technical viewpoint. It is essential that the complete requirements for the vessel are clearly known in detail and that the project team is conversant with the marine world and has experience of floaters and the requirements of various governmental agencies.

REVIEW OF DESIGN ASPECTS

Fulmar FSU

Conversion of *Medora* to an FSU for long-term operation in the North Sea involved radical changes to suit the operational and safety philosophies which are already well established for offshore structures.

Accommodation

The decision to carry out such an extensive stripping-out of the original accommodation within the superstructure block was taken principally because of the necessity to replace all the original combustible bulkheads, linings and asbestos ceilings with non-combustible materials, complying with the latest offshore SOLAS 1974 requirements.

In conjunction with this fundamental decision, the opportunity was taken to revise the internal arrangement to comply with the standards for living quarters on offshore platforms, which also necessitated upgrading the catering and domestic services.

This radical refurbishment of the accommodation was a major item of expenditure in the conversion, but the benefits of operational conformity and extra hotel accommodation have been well proven in service.

Helideck

The siting of a helicopter landing area, which would conform to North Sea requirements, was one of the major design considerations of the conversion of *Medora*, with its location influenced by safety standards and the proximity of other facilities required on the FSU.

The choice of location, on top of the aft superstructure block in preference to a foredeck location, was made on the basis of it being in a 'safe' area, adjacent to the living quarters and protected from the harsh environment. This aft location did, however, lead to difficulties in the provision of supporting structure and in re-routing machinery exhausts to provide the regulation clear area of operation.

Since commissioning of the FSU on the Fulmar Field in 1981, helicopter operations have been maintained continuously as part of the general North Sea network, and the choice of location, affording direct access to living quarters, has proved successful.

Cargo and ballast systems

The 'five-tank' sub-division of *Medora* (see Fig. 5) was typical of VLCCs of the mid-70s and hence development into the fully segregated ballast tanks (SBT) requirements of MARPOL 1973/78 could not take place without affecting the available crude oil storage capacity of the FSU. An extension of the original permanent ballast tanks (PBT) system was therefore chosen to achieve the minimum draught and trim requirements stipulated by the model tests of the mooring system. This solution necessitated conversion of one cargo/ballast tank (No. 2 centre) and the forward fuel oil deep tanks to achieve the required ballast capacity.

Long-term conservation of these ballast spaces was to be achieved by using an epoxy paint system, involving the complete re-blasting and coating of the PBT, with the same protection for the new ballast tanks. Replacement of the original steel ballast lines with a new glass reinforced plastic (GRP) system was prudent for the long-term deployment of the vessel on the Fulmar field.

While this conversion policy of steelwork protection incurred a considerable proportion (about 13%) of the total conversion budget, its value in maintaining effective corrosion protection has been proven.

An alternative option of converting Nos 2 and 4 cargo wing tanks to SBT, while offering a greater degree of protection in the event of contact damage at shipside, would have reduced the amount of available oil storage capacity by 12% and increased the cost of steel conservation by 80%.

In future conversions, where of necessity older tonnage will be considered for storage units, the optimum choice of vessel must have a tank layout containing adequate sub-divisions of wide clear centre tanks for crude oil storage capacity and relatively 'narrow' wing tanks for ballast.

The crude oil storage capacity on the Fulmar FSU was designed to cater for a high loading rate of 180 000 barrel/day (b/d) production and as such had a designated reception tank of 128 000 barrels capacity, followed by gravity distribution into selected storage tanks. This arrangement was designed to allow unrestricted flow (apart from the emergency shut-down (ESD) valves) from the production platform to the FSU and also to provide a back-up separation tank in the event of any water carry-over from the process plant.

Directly connected with the crude oil storage system are the associated inert gas and crude oil washing systems, and while these have operated successfully at the design flow rate, there are some shortfalls in performance. The tank washing system in particular was designed for one cargo every two to three months, and subsequent tank bottom build-up. In the Fulmar FSU, with constant production, bottom build-up has been obviously greater. For future conversions, a larger more comprehensive tank washing system would be fitted to eliminate the problem.

In-tank maintenance has highlighted the need for complete flexibility of the pipeline systems, coupled with adequate valves to ensure total isolation of individual tanks as required for safety of personnel and deployment of equipment.

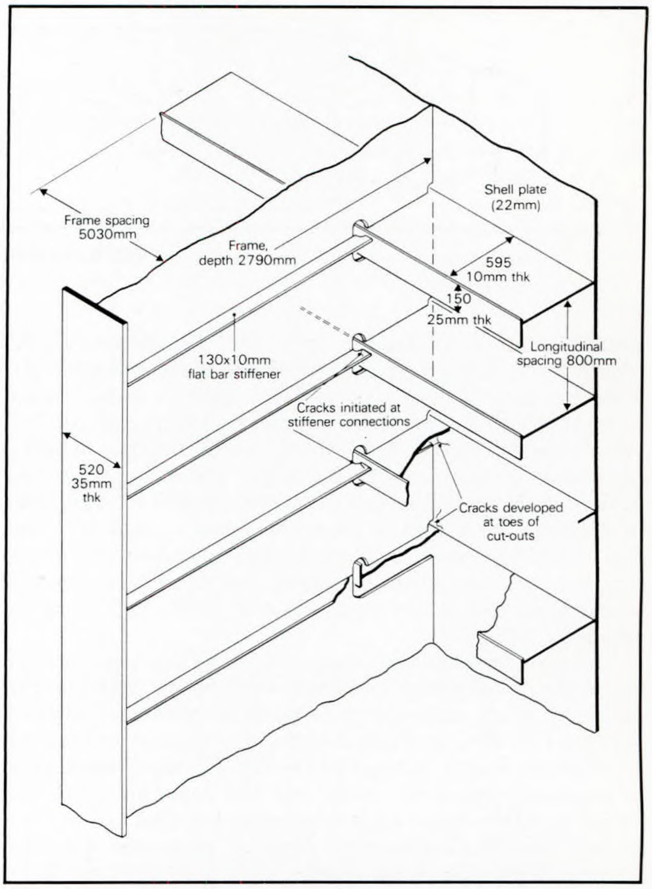

FIG. 6: Typical structural design of Fulmar FSU

Cargo tank structural integrity

Four years of continuous operation in a hostile environment such as the North Sea endorsed the value of providing a well found vessel for conversion to an FSU. Choice of vessel for this project was made on the basis of its existing cargo and ballast tank protection as well as its proven structural design, which was subjected to an extensive examination during the conversion, with suspect connections in vulnerable areas of the tanks being suitably reinforced. Typical of such defective connections were those between the shell longitudinals and web frames, above the turn of bilge area and in many of the wing tanks.

Subsequent in-service inspections have revealed an extension of these fatigue fractures, mainly within the midship ballast tanks, necessitating further reinforcement in this area. These connections, as shown in Fig. 6, are typical of structural design in the era when the vessel was built and have now been recognized as a potential source of fatigue fracturing in service, thereby requiring increased reinforcement or re-design.

Problems of bottom plate corrosion by pitting is seen as the biggest danger to long-term operational life of an FSU, and although great efforts were made during the conversion to ensure that areas of paint breakdown were 'touched-up', this is still regarded as an item requiring regular in-service inspections.

In-service operation of the ballast tanks at varying ullage levels to suit continuous loading of the cargo tanks in the FSU has resulted in structural damage to the internal stiffening of the forward ballast tank from the movement of ballast across this wide tank space. Local buckling of the large flat plate areas in the corners of the top stringer flat has necessitated fitting additional stiffening in these areas.

Bow mooring connection

This area subsequently proved to be the most vulnerable to the harsh environment of the North Sea, and during the past few years has required a considerable amount of manpower and expenditure in terms of regular inspections and repairs to damage caused by wave slamming.

Design of the bow mooring connection, while totally adequate for the mooring forces anticipated, has not proved entirely suitable in deflecting the regular wave impact forces encountered as a result of its exposed location. Based on design criteria for the single anchor leg mooring (SALM), the hinge connection of the rigid arm to the FSU was located at a nominal 1.5 m above the maximum load line of the FSU. Unfortunately, on this vessel, the height of the connection also coincided with the narrowest portion of the bow contour, resulting in a requirement for an additional and wider structure at a position in front of the forward perpendicular to support a configuration of ship hinges and central thrust bearing in the same axial line.

A supporting structure, in the form of longitudinal cantilever girders port and starboard and a box-beam athwart ships, was 'built-into' the existing bow construction (as shown in Fig. 7) in order to attain full alignment and adequate re-distribution of the anticipated mooring forces. Owing to the substantial nature of this construction, it has resulted in the underside flat plating being exposed to excessive local wave slamming forces, above the levels anticipated for the increased bottom thickness, and the loadings have not been significantly reduced by the relief openings provided in the design. This problem was solved to some extent by fitting fairings to the structure at a recent docking.

The effects of this wave slamming can be felt throughout the whole structure of the FSU, in the form of a low-frequency whipping motion, and because of the height of the connection relative to the water level this has been very difficult to avoid in moderate or severe seas.

The only access between the FSU and the SALM buoy is via the rigid arm connection. Regular inspection and maintenance of the pipes and fittings is very difficult and restricted during periods of even moderate wave height when the FSU is fully loaded. Additional dynamic loading on the bearings and support structure is therefore continually induced in this wave contact zone, and adequate monitoring of their general condition has proved difficult.

In hindsight, it would have been preferable if the design of this particular SALM had been arranged with a ship hinge connection well clear of the load waterline, preferably at or above the upper deck level, in order to obtain greater benefit from the original bow flare of the vessel. Operational angles and design loading on the overall mooring system may have been affected by a modified design of this type, but would not have been unduly restrictive or resulted in any extensive changes to the SALM contruction.

In future designs, whichever type of permanent mooring system is proposed for an environment like the North Sea, due consideration must be given to the severe effects of wave slamming and suitable provision made for routine inspection and maintenance of the components.

Tazerka FPSU

Unlike the previously discussed conversion for long-term operation in the North Sea, this project for off the Tunisian coast was required on a much more economically and operationally uncertain basis, resulting in a different design philosophy from that followed for Fulmar.

With a field life expectancy of about six years at a maximum production rate initially of 10 000 b/d and a forecast increase in water content as field life increased, the offshore facility had to be self-sufficient in all aspects of production, storage and offloading but developed to be compatible with reliability and safety. The choice of vessel to fulfil this role was therefore limited to the older generation of VLCCs, readily available at competitive prices, from which *Murex* was selected.

Because of the above criteria, the conversion and subsequent operation of the FPSU has a number of less-than-optimum design features.

Cargo and ballast system

Again, the five tank sub-division on *Murex* (see Fig. 8) did not leave choice for the allocation of an SBT system to MARPOL 1973/78 requirements, apart from converting the existing cargo wing tanks (Nos 2 and 4 port and starboard) to achieve a measure of protective location. While this was of value when considering the side-by-side offtake operations, total ballast capacity available in these two sets of wing tanks (89 497 m^3) has been found to be greatly in excess of the FPSU's requirements, resulting in only partial filling of these spaces.

Steel conservation in these newly created ballast tanks, in view of the large surface areas involved (4 x 12 600 m^2) and the limited field life anticipated, was restricted to the installation of an anode system, evenly distributed over the uncoated steel structure. Partial filling of these tanks over the past three years has now fully depleted the anodes in the lower section, while causing relatively little consumption of those in the upper section. This has resulted in fairly extensive corrosion in this ullage space.

Increased potential field life has led to subsequent re-evaluation of the FPSU facility for a further seven to eight years service life and has therefore raised certain doubts about maintaining the structural integrity of these spaces without an extensive conservation programme being implemented. Considerable effort is now being devoted to developing the most cost-effective and practical solution to the problem.

In hindsight, this work would have best been carried out

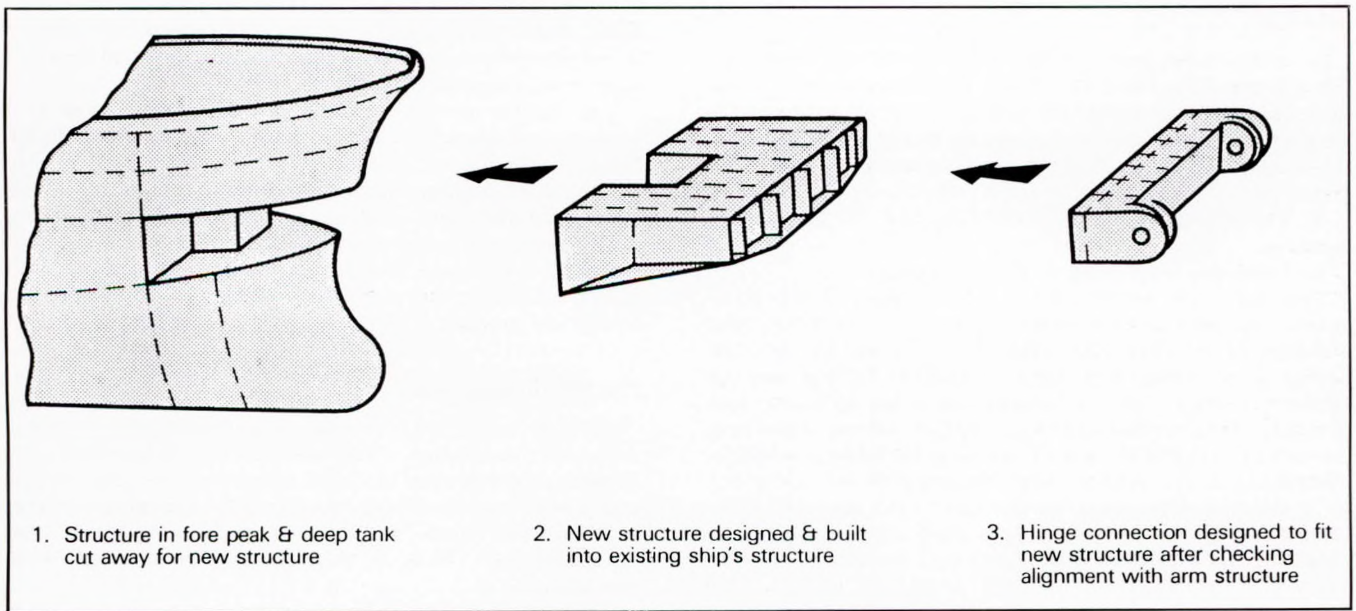

FIG. 7: Design concept of bow connection of Fulmar FSU

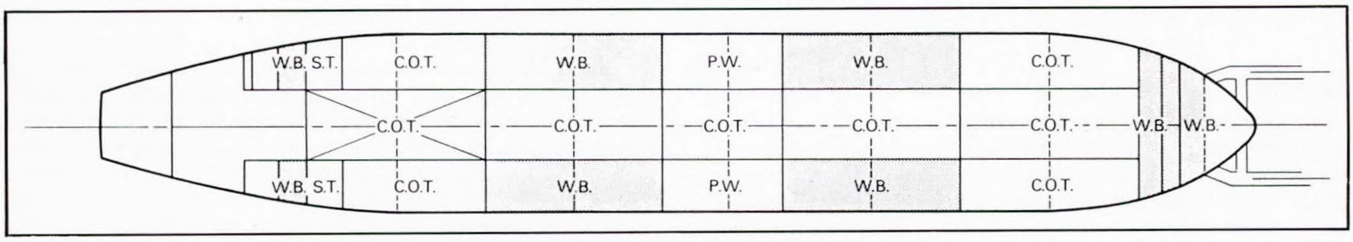

FIG. 8: Tank layout of Tazerka FPSU

during the conversion, had the service life of the facility been clearly established, and the benefits of selecting a vessel with smaller wing tanks or greater sub-division would have been recognized.

Cargo transfer system

In view of the field's low daily production rate, the FPSU's large storage capacity and the anticipated cargo lifting by conventional, non-dedicated offtake vessels, the transfer system was designed to be as simple as possible. The system was sited on the starboard quarter, with a steel gantry to support the cargo hoses.

This system had been used previously on the Castellon project, but the potential difficulty of handling the larger 12 inch diameter cargo hoses and 8 inch diameter bunker hoses in this way was not recognized fully at the design stage, and although this facility was reduced to three hoses (two cargo and one bunker), the ship-to-ship transfer and connections still present problems to the FPSU crew during offtakes.

The benefits of installing a purpose-built flow boom or hose handling crane at the conversion stage could have been a better solution from a safety point of view.

Accommodation

Since it was not necessary for this FPSU to comply with North Sea offshore standards, little of the original sea-going accommodation was modified. While not proposing the extensive re-design involved in the previous conversion, better modification of these spaces could have given greater flexibility and increased facilities during periods of on-going maintenance, if the longer field life now anticipated for Tazerka had been established prior to or during the conversion project.

ELECTRICAL AND CONTROL SYSTEMS

General

In vessels ranging from 60 000 to 220 000 dwt and designated for conversion to FSUs or FPSUs, the electrical and control systems have to be studied individually to ascertain the need to re-use or repair existing equipment, or to install new systems. The decision as to which of the two options to take is broadly based on:

1. The condition and expected future life of the existing material.
2. Economic constraints of the particular project.

On conversions so far undertaken, the policy has been to retain existing materials wherever possible. In theory this should lead to a saving on capital costs. In practice, the cost saving of retaining such items as existing cabling may be dubious in some cases as so much of it has to be cut and diverted, or new cables added to tray or ducting containing existing cables, that in terms of labour it would pay to make a complete renewal. Additionally, it is optimistic to expect that an existing installation can be shut down for a period of some months or perhaps a year, be worked upon and perhaps damaged and then perform well for maybe another 10 or 20 years.

Alternatively, to scrap possibly 100 or more pump motors does not make economic sense as it is possible to protect these motors during the conversion and use them again with no further risk to the installation.

Cabling

As mentioned previously, cabling is one of the biggest problems when converting a vessel. Some existing circuits will be abandoned, some modified and many used. On the Fulmar FSU, for example, over 400 km of new power and control cables were installed and almost all the existing cable (about 80 km) re-used. In 1980, installed cost was approximately £10 per metre; it can be seen that new cabling accounted for about £4 M and the saving, by retaining the existing cabling, would have been £800 000 plus the cost of stripping out the existing cable.

These rough estimates show that expenditure on cabling represents a large proportion of any electrical and control installation, and would probably be doubled today. The tendency is thus to leave the existing electrical cabling intact if savings can be made.

Control rooms

The positioning of a central control room has been seen as more important as one conversion has succeeded another.

When *Ildefonso Fierro* was converted for the Castellon field, the control room was in fact a cabin on the poop deck. The forward facing cabin was simply cleared of furniture and various fire and gas detection panels were installed together with VHF and telex facilities. The equipment installed caused overcrowding and clutter, and the room also suffered from poor visibility, as it was too low down and had no purpose-built windows from which deck operations could be scanned.

Subsequent conversions, notably the Fulmar FSU, recognized this problem and in the latter case the old wheelhouse was given over totally as a centralized control room. This gave the advantages of space, good all-round visibility and a quiet and safe area.

Invariably the wheelhouse will prove to be a suitable location because of its size and position. Another factor to be taken into consideration is that it is usually possible to isolate the wheelhouse in an independent fire zone, as the control room would obviously be an extremely important area during any fire-fighting operation.

Another possibility for the control room is the existing cargo control room where this is not part of the wheelhouse. Like the wheelhouse, it has advantages of position and fire integrity as well as possibly already containing some of the control equipment to be re-used. Usually, however, this space is not as large as the wheelhouse and cannot accommodate easily all the extra equipment required for offshore work.

One further possibility for a central control room is a purpose-built module sited externally to the accommodation block.

This can be perhaps the cleanest solution for internal equipment siting and layout, as no account has to be taken of existing obstructions in the room (ie pillars etc.). It does, however, create more problems in that it may have to be sited above a hazardous deck area and have to fit in or round process equipment on deck.

Electrical equipment

On tankers the use of electrical equipment on open deck areas has traditionally been limited. This has been partly because relatively little electrical equipment has been needed and partly because of the dangers of electrical equipment in hazardous areas. For many tanker operators it has been deliberate policy to keep flameproof equipment to a minimum.

With the advent of offshore storage and production units, much of the equipment now being installed has never been required on a tanker. Following the oil industry philosophy, the electric apparatus is suitable for use in hazardous areas, ie of a flameproof type.

There has been reluctance to use this apparatus by electrical and control engineers with a marine background, but in the new role in which the tanker finds itself the offshore operator employs maintenance teams qualified to deal competently with electrical apparatus. The 'permit to work' scheme is operated offshore and has proved, over a long period, to be very effective, ensuring that equipment is correctly and regularly maintained.

Cargo tank equipment

Cargo tank arrangement and use is invariably altered when a vessel's role is changed. This in turn leads to modifications to the pumping systems and the installation of extra control valves and/or modification of the existing control valve arrangements/locations. The actuators of the control valves may be powered by hydraulic or electric means. Using hydraulic control pipes on deck obviates the need for intrinsically safe circuitry, but on the other hand may be costly and prone to leakage and the need for maintenance. In either case there will be a significant installation cost and the control valve network must therefore be carefully designed. On one conversion there were over 300 valves to be controlled remotely from the central control room, and over 70 km of hydraulic control pipe was required.

Certainly any in-tank valves should be controlled from the central control room together with all essential valves on deck and in the pumproom. The next generation of cargo control may well see fully automatic load and discharge systems, but up until now executive action has always been required, with the control systems being used only for monitoring and surveillance purposes.

State of the art level and temperature measuring equipment have been used on each of the conversions so far undertaken by SIM, with remote readouts being available in the cargo control room. Currently, the microwave radar-type ullage systems are proving very reliable and accurate, but they must be set up and installed carefully to avoid any reflections from obstacles in the way of the radar beam in the tank. These can be used with any liquid and have no moving parts in the tanks.

Power generation

Inevitably, conversions with added equipment tend to require more electrical power and security of supply than that originally installed. While the loss of the main engine results in a lower base-load requirement, the addition of offtake equipment, large cranes, heating and cooling plant usually means that there are occasions when demands are higher than when the vessel was used as a tanker.

On both the Fulmar FSU and the Tazerka FPSU it was decided to install extra generating plant, but the problem was tackled differently on each vessel.

For the Fulmar conversion it was decided to supplement the existing plant with additional generators similar in output to the existing installation within the original machinery spaces. The existing steam-turbine-driven unit was removed and two new steam-turbine units installed. In addition, one diesel-driven generator set was added to the existing diesel set. Under most load conditions, one steam-turbine set would be used, but when offtaking cargo or using large cranage two sets would be operated. The diesel generators were stand-by units in case of steam plant failure or for maintenance periods. Automatic starting and synchronizing of stand-by generators was arranged and automatic load-sharing facilities provided.

For the Tazerka project, some process equipment required 3.3 kV and a different approach was adopted. Two diesel-driven generator sets were provided as a package unit in a prefabricated module. The switchgear was also provided in a deck module, and from this generation plant power was supplied to the ship's main switchboard via a step-down transformer. The existing diesel generator was used as a stand-by in case of loss of power for the ships services.

The problem encountered on Tazerka was that the process facilities were designed and equipment specified for a neutral earthed system, which was incompatible with the ship's existing three phase insulated system.

Future policy will probably adopt one of the following:

1. Use and strengthen as necessary existing equipment and contain all power plant in the machinery spaces if field life is short and minimum process facilities required.
2. If modular packaged units are employed, dispense with the ship's power plant completely and supply the ship's services only from the new unit, using transformers if necessary.

In each conversion, extensive modifications were carried out on the ship's existing main switchboard. If such a major conversion as Fulmar was attempted again, it would be prudent to renew completely the switchboard as the modifications and extensions for Fulmar were very considerable. When using existing switchboards problems can arise such as the fault level rating of the bus system.

When connecting in one or more extra generators, the bus bars will have to be strengthened or interlocks used to restrict the number of generators which can be connected at any one time.

It will be found in major conversions then that the neatest and perhaps safest thing is to renew the main switchboard, but this will depend on several considerations:

1. The amount of new generating capacity to be installed compared with that originally connected.
2. The age of the existing switchgear.
3. The physical constraints (ie room available in the existing switchboard location).
4. The type of main distribution system (ie compatible with existing plant or at a different voltage).

FIRE AND GAS DETECTION

Fire- and gas-detection systems are most important and rightly receive considerable attention both in terms of design and expenditure. The policy adopted on all conversions undertaken has been to equip these systems to the highest level possible and to cover all foreseen eventualities.

Fire-detection equipment has been installed throughout the accommodation areas, including all cabins, machinery spaces and pumprooms. Detectors for hydrocarbon gases and hydrogen sulphide have been installed at strategic points on deck and in air intakes to accommodation and machinery spaces.

All fire and gas monitoring is carried out from a purpose-built console room. Well defined zoning of the detectors is vital to ensure that when an alarm is sounded the operator can quickly ascertain the location of the alarm and take the necessary action. This means that the zones must be kept as small as practical so that an alarm will immediately indicate the precise area of trouble.

INTERFACES

For the vessel owner, interface problems usually relate to the fact that the conversion contactor has to integrate systems and equipment supplied by the owner or his sub-contractors into the overall design.

The conversion contractor expects that equipment supplied by the owner will arrive on schedule, be complete in every detail, preferably be factory commissioned and will have been preceded by reliable drawings, but this is often not the case. Often equipment and systems may not fit into the space allocated on the vessel, parts are missing on arrival, drawings are late in arrival, and sometimes the equipment is faulty or has not been properly tested. Project co-ordination must be strictly controlled if such problems are to be avoided.

Conversion contractors will take advantage of any of these problems to claim delay to their progress or press for extra installation costs.

Clearly owner-supplied equipment can be a major problem unless it has been thoroughly defined for scope of supply and delivery schedules etc. are strictly followed. Where time permits it is preferable to allocate in the contract the purchase of equipment and all its attendant problems to the Conversion

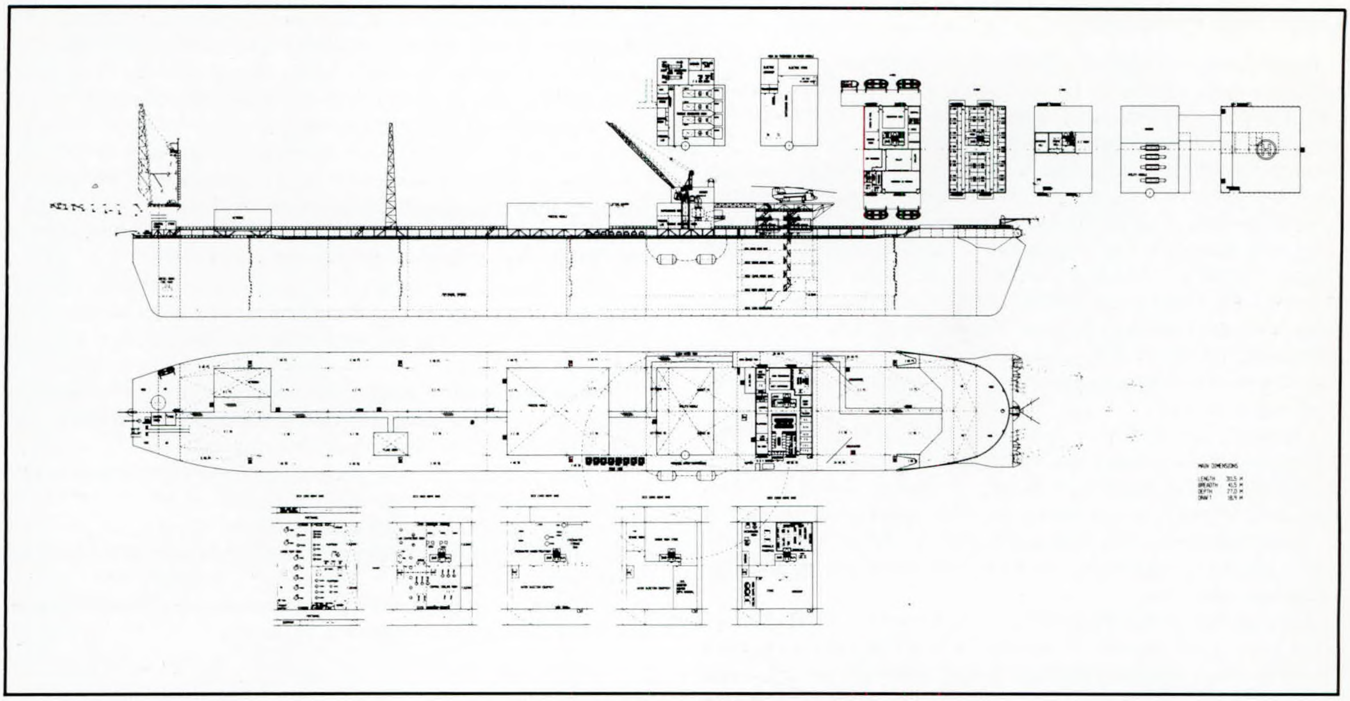

FIG. 9: General outline of new unit

Contractor, if he has the necessary infrastructure for such a burden.

OPERATIONAL ASPECTS

Examples of the problems which a changing scenario in relation to field production can give are highlighted by the experience on Tazerka.

The fitted production train consists of three separators, a crude oil pre-heater and a stabilizing vessel. During the post start-up phase the crude oil pre-heater proved superfluous. Consequently there was no requirement for steam for process heating, and the hotel load could be catered for by one of the diesel's generators.

In the original planning the auxiliary boiler which had been extensively upgraded was to have been fired continuously to supply heat to the process and other services. However, as a consequence of the lower steam load, it became possible to run the boiler only during export operations, gaining substantial fuel savings and reducing operating cost considerably. Had the field flow rate been recognized during the design stage, the steam plant conversion might have been unnecessary and the newly installed electrical power used more fully.

Operational experience indicates the following are changes which could offer advantages for SIM in future conversions.

When specifying a deck crane it is important that the boom be of sufficient length to plumb over the modules and walkway on either side of the vessel. There is a definite requirement to land gear, such as remote operated vehicle equipment, compressors etc., on each side of the vessel. For ease of transportation on board there should be clear passageway to the poopdeck and the forecastle deck, along one side of the vessel.

This has not been the case on conversions so far, and on many occasions has caused operational problems, eg when a crane barge had to be used to position Neptun steps to carry out hull repairs. Had the crane installed on board been capable of spanning the vessel, hire of the crane barge would have been unnecessary.

In future conversions breakwaters should be fitted in container landing areas. These should be of sufficient dimensions to provide protection from waves breaking on deck. While on the Fulmar FSU it is a standing instruction to empty the received containers and return them on the supply boat, this cannot always be done and a potentially dangerous situation could be created.

The fender systems on the floaters should be easy to operate to avoid a hazardous situation during fender retrieval. If it is not possible to have a dedicated supply boat, serious consideration should be given to an increase in the internal structure of the tanks in way of the landing space area.

It would be extremely advantageous in future projects, whether conversion or purpose-built floaters, if the operator could be involved at the conceptual design stage. This would also ensure that the operator understands fully the 'raison d'etre' which the project team followed, dictated by field constraints or budget, or a combination of both, and the partners' requirements.

PERSONNEL

Marine personnel from Shell Tankers (BV) Ltd were recruited for the Tazerka project, but could have been recruited from any of the Group Fleets. The objective of this choice was the availability of multi-skilled marine officers with considerable ship management experience. Marine personnel have proven that they can also become valuable production personnel. Their high personal motivation and familiarity with being offshore for extended periods are obvious advantages.

The team established for the Tazerka project was given six weeks basic production training at a Training Centre. Operators benefitted from involvement in the final commissioning and were of great assistance to the site project team.

Flexibility and versatility are the most important requirements for running a converted tanker. Contrary to normal production procedures, Fleet technicians also conduct maintenance on the installation so that experience of the tools used is necessary.

In the future a flexible workforce, ie operations technicians, is desirable. An extensive training programme is presently underway on the FSU to cross-craft the technician workforce, thus adding the flexibility factor necessary to achieve a more efficient workforce.

THE FUTURE

The outlook for floaters has changed recently with the fluctuations in oil prices, with the larger FPSU becoming less attractive while the lower cost unit has become more appropriate for strictly marginal fields.

Whilst SIM is conversant with the conversion of the semi-submersible for use as an FSU or FPSU, greater attention is being paid to future use of the monohull. There are the two distinct scenarios: conversion of existing tonnage and newbuild.

Conversion of existing tonnage must by necessity mean taking a vessel that is probably a minimum of 10 years old, and also built with reduced scantlings. Since even pessimistic projects may extend their life by years rather than months, a conversion should be planned on a minimum of 10 years station life.

With such a time span it means the original machinery will be 20 years old at project end. Working from the premise that a converted tanker or newbuild is used purely to store oil, process crude, and then export by some means of offtake and also possibly act as a flotel for the field, we consider the converted vessel should be made as watertight as possible, ie remove the shaft and reduce sea openings to a minimum.

In the case of a conversion, the use of existing equipment, the extent to which accommodation has to be upgraded, and the use of a new power plant fitted on the deck have already been addressed. For a conversion it would be advisable to use as little as possible of the old equipment, to eliminate the steam plant if fitted and use electric motors or hydraulic power for cargo pumps. Ideally the cargo piping should be renewed but this is not usually possible; fitting of extra valves is therefore advised to enable pipelines to be renewed or maintained in service. Tanks must be protected against corrosion, and painting the tanks in the upper and lower areas is advised to reduce the corrosion problems as the field life extends.

A newbuild floater has been studied by SIM and E&P. In the future some changes would be made to the study's conclusions to meet the developing needs of a marginal field, and also to fall in line with experience in various worldwide operations, but especially the North Sea. In general the hull will be used only for the storage of ballast and crude, pumping would be attained by a deep-well pump for each tank, the power unit and accommodation will be of modular design and sited on the upper deck, and the space below the accommodation, which at present is a gas-free area, could be used for machinery requiring real protection from the sea. The general outline of such a unit is shown in Fig. 9.

Discussion

Captain J. A. SMITH: Cargo transfer 'off-take' appears to have been the least of the authors' problems, but it would be interesting to know more of the securing, or mooring, the fendering, and the hose handling systems in both North Sea and Mediterranean conditions.

Mention of 8 inch bunkering hoses calls to mind a paper in the April Symposium, in another place, on 'Marginal and Deep-water Oilfield Development'. It described the construction of a system to use crude oil, safely, as fuel. This contributor's Pavlovian reaction to the very idea earned a reproof from a younger companion, who pointed out the undeniable economics of doing without the purchase and handling costs of special bunker fuel, which might well outweigh the cost of the additional equipment required to make the system safe. Would the authors say if they have ever seriously considered the use of crude oil as fuel, and if they have ever costed it, however roughly.

A. C. HYSLOP (Chevron Shipping Co): I would like to ask the following questions:

1. When selecting a vessel for conversion, would one be preferred with an uncoated bottom internally in way of cargo tanks or a vessel with an internally coated bottom, at the risk of needing many repairs to small but very deep pits?
2. Having selected a vessel, would the bottom be coated internally?
3. If the vessel is to be coated internally, what type of coating is preferred on the bottom plates?
4. Having coated the bottom, what precautions would be required to prevent damage to the coating while work is carried out in the tanks?

D. W. SMITH (Bureau Veritas): Considering the extreme weather conditions demonstrated in the video film, would the authors please comment on whether any adverse affects have been noted on the yoke bearing arrangements and advise what type of bearings were used.

J. W. WETHERED (Floatech): Some years ago whilst working for Lloyd's Register of Shipping, I was involved in the structural re-analysis of the Fulmar FSU end beam following slam damage. Initial calculations suggested that the underside of the beam had been subjected to very high pressures. At the same time that these calculations were undertaken Shell commissioned in situ measurements to be taken in way of the damaged areas and the values obtained correlated reasonably well with the calculated values. Using this information it was then possible to apply realistic loading conditions to the large 3D finite element model used for the re-analysis.

Shell have commissioned model tests in orer to ascertain the effects of fairings fitted under the beam in order to reduce slamming and the results presented at this meeting show a significant reduction in the peak pressures resulting from wave slam. Could the authors advise whether it is Shell's intention to follow this work up with in situ measurements in order to confirm the effects of the retrofitted fairings.

Despite the damage which occurred to the beam, it may be worth noting that because of the careful design of the beam/hull connection regarding continuous longitudinal structure, the structural integrity of the system was not compromised and was able to continue operating until the planned field maintenance period, at which stage the above mentioned modifications were carried out.

Author's reply

In reply to Captain Smith, experience gained from cargo transfer operations on the various storage units is now quite considerable and could form the basis of a paper in itself.

In Shell Seatex we have not seriously considered the use of crude oil as a fuel in projects with which we have been involved. The burning of gas separated from the production of crude oil has been studied and applied to boilers, the technology and security being similar to that for gas carriers. The economics of using gas have to be evaluated for each case to see whether the initial investment in extra equipment can be recovered in reduced fuel oil bills over the life of the project.

The use of crude oil as a fuel presents similar safety problems, in some respects, to gas burning without the benefit of clean combustion. In fact in many applications the quality of the crude can vary from day to day, not least in its water content and flashpoint, hence the problems in its safe handling and combustion, which are not necessarily insoluble.

In response to Mr. Hyslop, bottom shell pitting on tankers is generally related to cargo/ballast operations or water 'drop-out' from the crude oil, therefore elimination of either condition by segregated ballast tanks and adequate water separation techniques will go a long way in helping the situation generally.

Direct replies to the questions raised by Mr Hyslop would therefore be:

1. As an uncoated bottom requires extensive visual and thickness survey to determine the actual condition, vessels with intact coatings would be preferred as cleaning for inspection and repairs is generally easier to carry out and any minor defects can be dealt with successfully.
2. As stated previously, coated bottoms make cleaning for inspection generally much easier when it comes to periodic surveys, therefore the investment can usually be justified for long-term operations.
3. For crude oil storage, coatings of coal-tar epoxy at thicknesses of 250 μm dft have generally been successful.
4. Prevention of damage to paint coatings by other activities is one of the most difficult tasks to control and requires constant vigilance and attention to ensure an effective protection system.

In reply to Mr Smith, the types of bearings used for the SALM connection on the Fulmar FSU are of a self-lubricating, spherical type for the radial bearings at the ship hinges and of a multi-roller type on the roll-shaft connection. During the 1985 docking, the opportunity was taken to examine all of the bearings within the yoke assembly and for prudence sake new ones were re-fitted for the continued lifespan of the project.

Extensive analysis of the condition of the original bearings has been carried out and the results are being related to weather conditions and loading forces experienced on site, as compared to design predictions.

In response to Mr Wethered, when the Fulmar FSU was commissioned in 1981 a comprehensive stress monitoring and motion data recording system was introduced in an attempt to gain some knowledge of the environmental loads being experienced on site. Problems have been experienced with analysing the recorded data from the various locations on the SALM structure. However, the whole system was revitalized at the 1985 docking in order to assess the effects of the 'bow-fairing' in reducing slamming loads on the bow connection.

It is hoped that this information gained on site could be re-created on a model scale whereby greater confidence could be established in predicting the range of environmental loads likely to be experienced on this type of floating storage unit.

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