AN EXPERIMENTAL STUDY OF FLOAT TYPE LNG TERMINAL

ETUDE EXPERIMENTALE DU TERMINAL GAZ NATUREL LIQUIFIE DE TYPE FLOTTANT

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ABSTRACT

The increase of energy consumption and stringent requirement of environmental protection stimulate the demand for the clean fuel with less carbon, i.e., natural gas.[1] The concept of LNG FPSO is considered to be advantageous, for distant offshore gas fields, without the necessity of permanent rigs nor undersea pipelines, and also feasible for the development of small or medium scale gas reserves, from viewpoint of flexible towing capability, comparing with conventional onshore liquefaction plants.

The technology of LNG FPSO has been repeatedly studied, and many engineers found that there were several measures to be solved from both economic and technological aspects. The recent progress of technology, however, made it possible to apply very simple and economical design for the LNG FPSO. The LPG FSO in similar relationship with the LNG FPSO was completed and recently delivered to African west coast for the service.

The design of LNG FPSO is completed, whose capacity corresponds to those of most modern onshore liquefaction plants. The testing of model tank has been conducted to confirm the wave excited barge motion in addition to the numerical approach, and various tests also were carried out to evaluate the performance of process plant focusing on the efficiency of columns due to equipment sizes, packing materials, motional types and so forth. The radiation of flare stack was studied to secure the plant safety aspects.

This paper is to present various aspects of the LNG FPSO design together with the results of model tests etc.

RESUME

AN EXPERIMENTAL STUDY OF FLOAT TYPE LNG TERMINAL

L'augmentation de la consommation d'energie et les conditions rigureuses prevues pour la protection de l'environnement stimulent la demande pour un combustible propre presentant une teneur inferieure en carbone, c'est-a-dire le GNL

Le concept de la FPSO GNL (unite de chargement au large et stockage de production flottante) est considere comme etant avantageux pour les champs de gaz eloignes "au large" sans la necessite de tours de forage de production permanente ou de pipelines sous-marins, et ceci est egalement faisable du point de vue de la capacite d'enlevement, pour le developpment de reserves de gaz de petite et/ou moyenne taille, compare a l'installtion de liquefaxtion "a terre" fixe du type conventionnel. La technologie de la FPSO GNL a ete etudiee plusieur fois et nous avons remarque qu'il y a eu moyens de resoudre du point de vue economique et/ou technique. Mais des progres technologigues recents ont rendu possible l'application d'une conception economique et tres simple pour la FPSO GNL.

Recement, comme produit se rapprochant de la FPSO GNL, la LPG FSO (unite de chargement "au large" et refrigerante flottante) a ete construite pour servir au large des cotes de l'Afrique Occidentale. Sur la base de ces progres, nous avons complete une etude de la FPSO GNL, dont la capacite correspond a un train d'installtion de liquefaction "a terre" moderne.

Nous avons ensuite effectue des experiences de test de reservoir a vagues des pontons dans les vagues, en outre de l'approche numerique. Nous avons aussi enterpris divers tests de simulation pour evaleur le rendement des equipments d'installation de procede en nous concentrant sur l'efficacite des colonnes, en nous basant sur le type de colonnes, le type de mouvement, etc., dans le mouvement de corps flottants en mer. La radiation de cheminee a torche a ete aussi etudiee du point de vue de la securite de configuration.

Ce document a comme but de presenter les divers aspects de la conception de la FPSO GNL ensemble avec les resultats du tests de modele, etc.

INTRODUCTION

With the growing global environmental concerns like CO_2 emission reduction treaty negotiation, the LNG demand is forecast to increase as a clean and less carbon content energy source. It is estimated, however, that the natural gas supply will be tight enough to encourage natural gas exploitation even in remote areas where meteorological conditions are harsh and/or hostile. For the offshore gas development, float type LNG terminals, generally called as LNG FPSO is one of the attractive alternatives, because LNG FPSO saves long expensive undersea pipelines and long berthing pier construction as it is positioned near above the offshore gas field in a proper mooring system.

The LNG FPSO had been discussed seriously more than a decade ago, and was abandoned due to the absence of suitable tank technology at that time. IHI developed as LNG carrier with self-supporting prismatic shape IMO type B LNG tanks (SPB tanks), constructing two SPB LNG carriers[7][8] and one LPG FSO[6] (with refrigeration facility) successfully operated and achieving the high performance.

Recent studies at IHI have proved that the LNG FPSO using SPB tank system would be justifiable both technically and economically for the future needs, completing a conceptual design of capacity corresponding to that of most modern onshore liquefaction plants. And various scaled model simulation testing for both vessel and plant related matters have been conducted in order to confirm the influence to the performance due to wave-excited motion in harsh conditions. It is pointed out also that the installment of a compact and safe flare system must be a key technology for successful LNG FPSO, which is significantly different from conventional onshore plants, and radiation heat distribution study is also carried out from the viewpoint of plant safety.

This paper is to present various aspects of the LNG FPSO features and conceptual design result of 2.5 MMTPA FPSO which is of single train plant with high availability by redundant system and equipment, and is of compact layout by using aeroderivative gas turbines, and is of safe layout by reducing flare volume etc. This paper also presents model testing results, discussing the performance influence and operational philosophy due to wave-excited motions.

FEATURES OF SPB LNG FPSO

Technical papers on the SPB FPSO have already been presented at various international conferences[(2),(3),(4)]. The planned SPB LNG FPSO has a liquefaction plant on the flat upper-deck of a barge and storage tanks below the deck, fulfilling the outstanding features of the SPB system, which can provide a very flat deck over the tanks holding safely LNG without any sloshing phenomena at any liquid level. The FPSO should be tied to a single-point mooring system installed near a gas field, and receives raw gas through a subsea pipeline. The subsea pipeline and the FPSO are interconnected by a flexible riser pipe to feed the natural gas to the FPSO, being allowed to head into the wind and wave as it can turn freely around the mooring point (weathervaning effect). LNG carriers can be moored alongside of the FPSO for offloading in principle, and under rough sea conditions, might be moored in tandem by stern and bow to receive LNG.

OVERALL FEATURES

The FPSO has the following features compared with conventional onshore plants.[(5)]

(1) It offers a low-cost solution by taking into account the multiple development of gas fields, compared with the conventional offshore gas field development designated to a single gas field.
(2) Long-distance gas pipelines from offshore fields to onshore plants are not required.
(3) The plant and tanks are pre-commissioned at the shipyard and towed close to a gas field, minimizing the site work. No onshore works, accordingly, are necessary.
(4) It can be moved to other field, after the depletion of a certain gas field. The relocation work can be only limited to the re-installation of a new mooring system, a riser pipe etc.

When planning the FPSO, the SPB tank system has the following better advantages than other tank systems.

(1) The liquefaction plant can be operated satisfactorily at any storage level in tanks, by causing no problem of wave-excited sloshing at any liquid level.
(2) It can provide a flat-topped deck on which to arrange the plant equipment and pipings freely.
(3) High operational safety because of the high structural strength against positive

and/or negative pressures.

(4) Its high space efficiency can make the FPSO dimensions smaller than others.

(5) The flat deck and adequate clearances between tanks and the hull facilitate the inspection and maintenance works.

CONSIDERATIONS FOR LIQUEFACTION PLANT DESIGN

The following factors when executing the liquefaction plant design, must be taken into account for the successful FPSO.

(1) Measures against the wave- and wind-excited motions

Explicit considerations must be taken to fractionation and absorption columns, other vessels and heat exchangers, which require level controls, as being affected by the continuous barge movement under the influence of wave and wind.

(2) Marinization measures for plant equipment

Paintings and corrosion protections for major equipment exposed to a salty environment must be formulated for the design life of 20 years.

(3) Communication and logistics support

Since the FPSO is positioned in an offshore gas field probably remote from the onshore, sufficient spares and necessary tools must be stored on the barge. And simultaneously, the reliable communication system to the onshore station is to be incorporated.

(4) Redundant and integrated design

The redundant units must be installed, as availability figures are more important in the FPSO than in onshore plants due to the unscheduled plant shutdown under climatic conditions. And equipment must be arranged as necessary clearances for safety, operability, and maintainability, with the provisions of cranes for mounting /dismounting those.

(5) Reduction of flare radiation

The intensity of flare radiation, even if a large quantity is relieved, should be reduced to the specified limit. Otherwise it might be necessary to install flare stacks on the independently separated barge from the FPSO.

(6) Applicable rules and standards

As there are no rules and/or regulations governing the entire LNG FPSO, those which are applied to the conventional onshore plants shall be employed.

The number of unavailability days is to be estimated, based upon the meteorological and oceanographic conditions of a specific site. It is calculated, for example, that the unavailability due to weather would be approximately five (5) days per year in the Timor Sea, where the IHI-built Oil FPSO is now operating.

PLANT LAYOUT AND SAFETY

The process equipment are installed on the upper deck safely against spill and gas leakage accidents and for the easy maintenance and servicing. The utility equipment like pumps etc. are arranged under the deck. The clearance around each piece of equipment is decided to meet the requirements of applicable rules and regulations.

The height of flare stacks, which are used to burn the gas exhausted from the plant equipment and tanks under startup and shutdown conditions for the safety of plant operators as well as process equipment, is determined to ascertain the heat flux lower than required thermal radiation levels.

(1) The two types of main cryogenic heat exchangers are present, and a coil-wounded type is selected in this study, which is installed on the flat upper deck.
(2) The refrigerant compressors and prime movers are installed on the deck also, for the ease of handling. The aero-derivative gas turbine of GE LM6000 is adopted in consideration of the limiting constraints of the FPSO, and it has the following features compared with most experienced GTs in onshore plants.
    - High thermal efficiency yielding less fuel gas consumption
    - Quick start and easy operation
    - Easy Inspection and maintenance, by the module exchange concept
    - Compact and light weight

Safety measures for the LNG FPSO are incorporated in addition to those required for the ordinary onshore plants.
(1) Spills of cryogenic liquid are guided to a safe area and treated safely. Compartments installed with gas appliances are isolated for safety assurance, and are equipped with ventilators and gas detectors.
(2) The gas turbines are installed to windward in principle for isolation from gas sources, or at adequate distances. The flare stacks are installed on the opposite side from the LNG carrier berthing side.
(3) Gas detectors and alarm systems are arranged in required areas, with the consideration given to the characteristics of leaking fluids, possibility of leakage, and importance of equipment, etc. Alarms are installed in the control room and in accommodation areas.
(4) The fire prevention and extinguishing facilities are planned similarly as for the onshore plants and marine experiences.
(5) The same emergency shutdown system is adopted as used in the onshore plants and ships.
(6) Every area is provided with at least two (2) exits for easy escape, and such exits are connected to two (2) or three (3) refuges via shortest escape routes.

Some equipment cannot be operated in stable manner due to decrease of performance under rough weather conditions and it is necessary to suspend receiving raw gas supply and shift the plant to standby state as the circumstances may require in advance by obtaining meteorological information.

OPERATION AND MAINTENANCE

The service availability of the FPSO is governed by the same factors as in onshore plants, except for peculiar downtime due to offshore weather conditions. Any docking for the maintenance of the hull are unnecessary throughout the life. The SPB tank system is of maintenance free, and the ample spaces between the tanks and hull offers easy and sure inspection to confirm the soundness of the hull and the completeness of SPB tank system.

To increase the availability, redundant units are installed as standby spares, like a standby GT generating unit, and 98% of availability is expected for the FPSO except for the above-described downtime.

Cranes are provided on the deck for relocation of equipment for inspection and maintenance purposes. A maintenance shop including spares' storage is also equipped on the barge to make some repair services except in special circumstances. The maintenance of the turbomachinery is conducted as exchanging the necessary module, and heavy maintenance works would be made in designated manufacturers' shops on land.

2.5 MMTPA LNG FPSO

The conceptual design of 2.5 MMTPA LNG FPSO was developed under the following conditions.

■ Feed Gas	Pressure		5.5 MPa
	Temperature		40 ℃
	Composition	C1 (%)	75
		N2 (%)	4
		CO2 (%)	6
■ LNG Production			2.5 MMTPA
	Impurities	N2 (%)	Less than 1.0
	Heating Value	More than	42 MJ/Nm3
		Less than	44 MJ/Nm3
■ Storage System		LNG	150,000 m3
		Condensate	10,000 m3
■ Meteorological Conditions		Mild	

To meet the requirements, principal dimensions of the barge are settled as follows.

■ Length	295 m
■ Breadth	60 m
■ Depth	25 m

The overall layout is shown as in Fig.1 and 2, and the flow diagram of liquefaction processes is illustrated in Fig.3. The feed raw gas is passed through the acid gas removal unit to remove carbon dioxide, hydrogen sulfide and other acid gases. The gas is further treated through an adsorption process for the removal of water vapor, and is introduced to liquefaction unit to make LNG, which is stored in the SPB tanks. The mist separated from the raw gas and high-molecular liquid separated in the liquefaction cooling process are fractionated, part of which is utilized to make up the refrigerant mixture and the remainder is stored in the SPB condensate tank.

In the conceptual design study, the well proven mixed refrigerant cycle was applied. For this cycle, several different processes are available from various process suppliers and the IHI-built LNG FPSO is very flexible to adopt any process cycles which are also prospective and successfully applicable except for rich experiences. The mixture of process gas itself and boil-off gas from the storage tank, are used as the fuel for the gas turbine drivers to meet the heat value requirement.

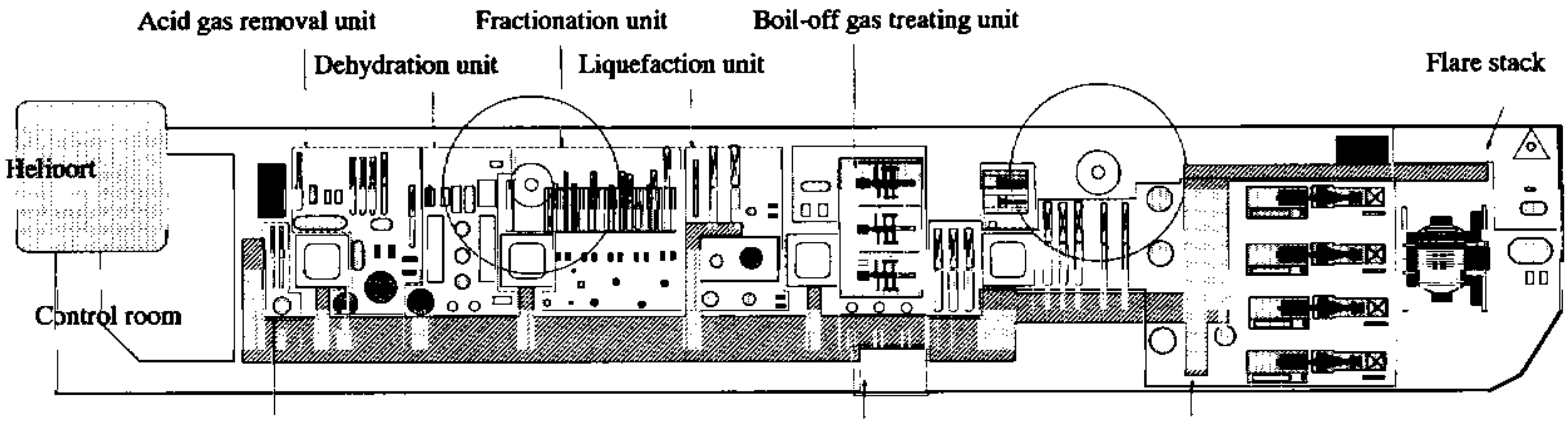

Fig.1 Typical Plan View of SPB LNG FPSO

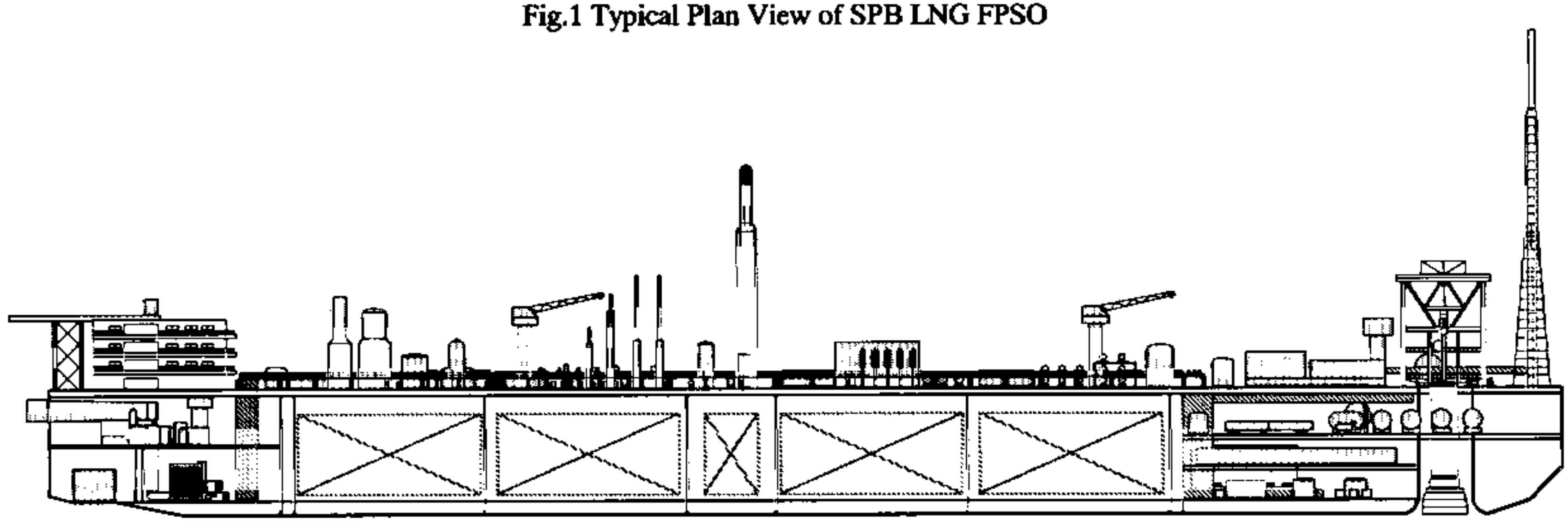

Fig.2 Typical Elevation of SPBLNG FPSO

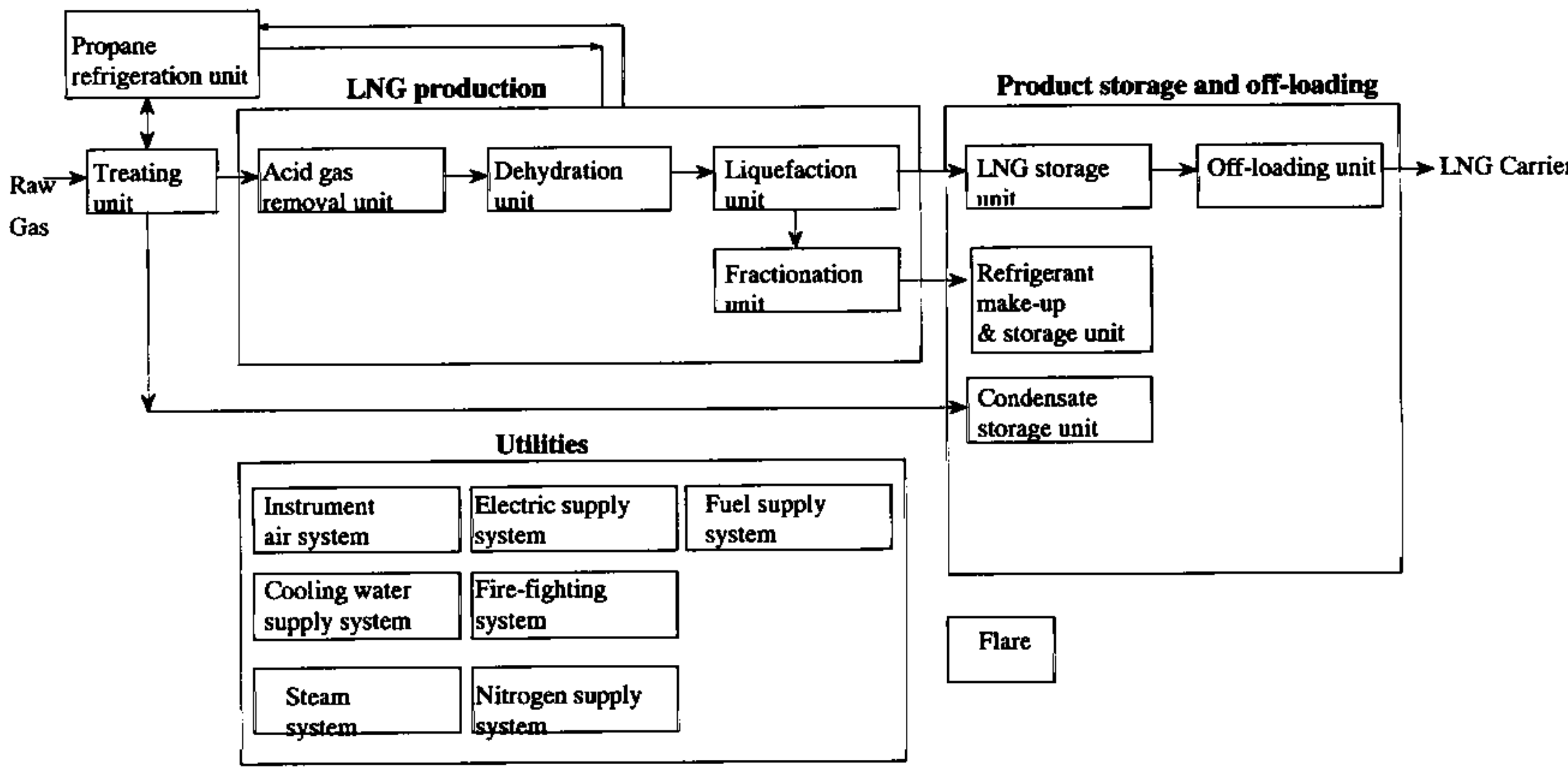

Fig.3 Typical Flowsheet of Natural Gas Liquefaction Plant

The seawater is used as the cooling media, to minimize the plant space. The drinking potable water and other fresh water supply are produced from seawater. The electricity is supplied by LM6000 gas turbine driven generators, which are also of double redundant system and installed on the upper deck, to feed process equipment drives, controls, and accommodation utilities. In addition, a Diesel engine driven generator is installed in the machinery room on the lower deck, as an emergency power supply.

The FPSO is equipped with motor driven stern thrusters that are used to bring the barge in line against the wind and current directions. The SPB tanks can be located efficiently in the space under the deck. The offloading system is installed at the alongside on the deck in the study, however, it is possible to relocate that at the stern with the modification of plant layout.

The process equipment are installed on the deck for safety against gas leakage accidents and for the ease of maintenance and service workings. The single tall main heat cryogenic heat exchanger is located around the center area on the deck, which is confirmed to be mounted by the shipyard crane facility. The refrigerant compressors and the drivers are installed around the bow area on the deck for ease of handling, which are of parallel running to keep turndown ratio capacity as high as possible. The boil-off gas (BOG) compressors and drivers to handle BOG from the tanks are also installed on the deck.
The utility equipment are arranged under the deck, except for the GT driven generators which are installed near GT compressors on the deck.

The flare stacks including tank flare are arranged at one relatively safe post, i.e. the bow area in the FPSO, the height of which are limited to 100 meters maximum, taken into consideration the easy installment and the motion stability of the FPSO. The radiation intensity of the flame does not exceed the required figures specified by API standards.

The safety measures for the LNG FPSO are incorporated in the following manners.

(1) Spills of cryogenic liquid are guided to a safe area.
(2) Gas turbines are installed to windward for isolating from gas sources.
(3) Gas detecting and alarm systems are arranged for the gas receiving area, LNG unloading are, fluid handling area, storage area, control room, accommodation area etc.
(4) Two exits for easy escape are provided for every area, connected to two refuge shelters.
(5) The fire fighting and extinguishing system, emergency shutdown system and others are planned as for the onshore plants.

EXPERIMENTAL STUDY

PERFORMANCE INFLUENCE DUE TO EXCITED MOTION

It would be suspected that the performance of absorption, fractionation and other columns, inside which contain the delicate contacting surface of gas and liquid phases, might be influenced by the oscillation which have impacts especially on the liquid surface stability. In order to minimize such impacts, it is important to select the best suitable packing internals for the successful FPSO, resulting the minimal plant shutdown and safe plant stopping due to anticipated big stormy weather conditions.

The flow schematic of a motion testing is shown in Fig. 4, and the general view of the testing apparatus in Fig.5. The model column is the simulated carbon dioxide absorption tower, and the particulars of which are listed as follows.

- Outline dimensions 500 mm ϕ x 4,000 mm H
- Type of column Random packing of stainless steel (IMTP50)
- Height of column 2,000 mm H

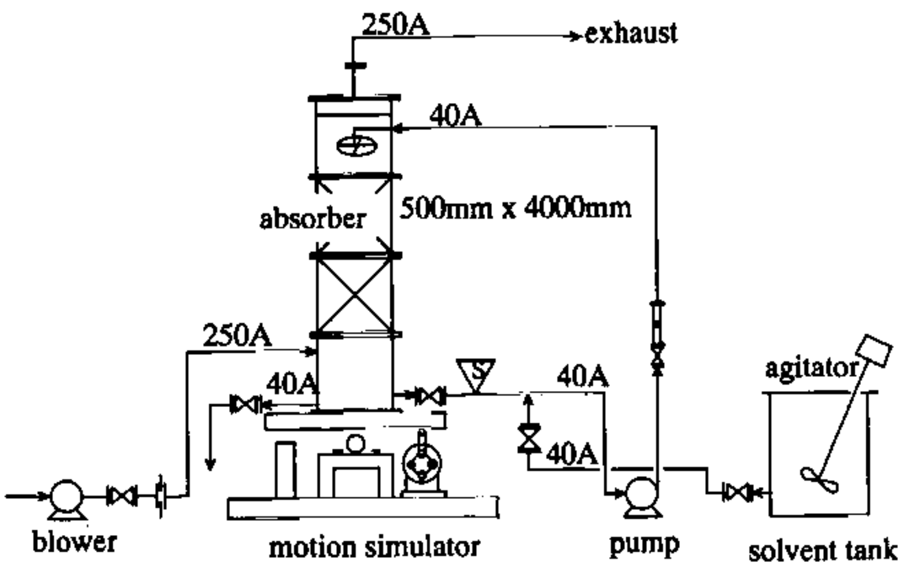

Fig. 4 Flow schematic of model testing for motional influences

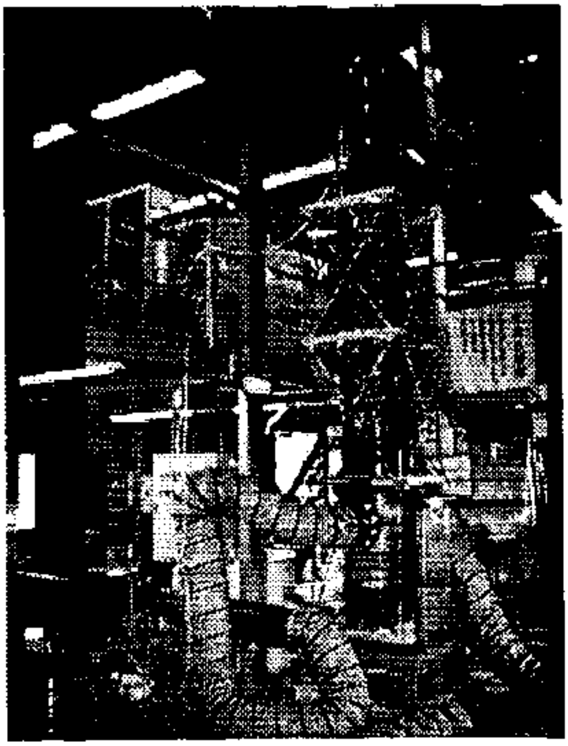

Fig. 5 General View of Testing Apparatus

The performance has been examined by measuring the oxidation reaction rate of water soluble Na2SO3 by the atmospheric air. The mixture of Na2SO3 and water is fed from the top of the tower, and the oxidation is reacted by the air introduced from the bottom. This has been confirmed by the content of $SO3^-$ ion.

The testing conditions are as follows.

- Air flow 500 ~ 1,500 Nm3/Hr
- Water flow 5 ~ 15 kl/Hr
- Amplitude 0 ~ 6 deg.
- Cycle time 8 ~ 15 sec.

The result of the performance influence by permanent inclination shows as in Fig. 6 that the degradation occurs due to the maldistribution of water flow, and such tendency would be accelerated in variation with the inclination angle. It is estimated that the performance degradation may be considered as trivial for the FPSO operation in the range of 2 deg.

These results would have almost no impacts when proceeding the basic design of LNG FPSO, because the FPSO is settled all the time just horizontally on the surface of the sea.

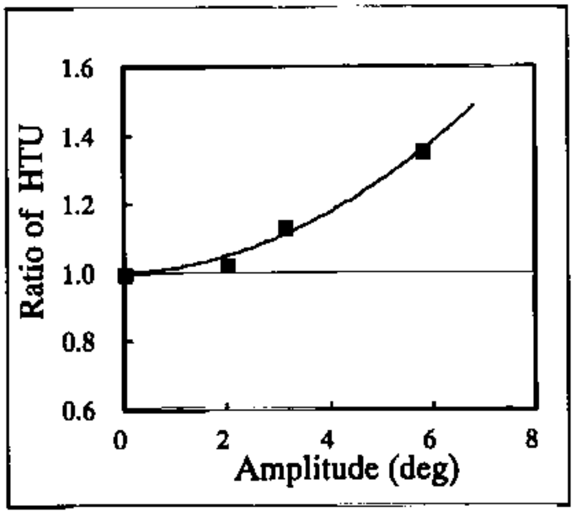

Fig. 6 Performance Influence by Permanent Inclination

It is measured that the performance improvement is occurred in the case of oscillation motion testing as in Fig. 7. This improvement is independent of the amplitude figures, and is getting more in variation with L/G, i.e., the ratio of a liquid flow rate (L) to a gas flow rate (G). These results were estimated by the more active reaction occurrence from the turbulent liquid surface mixing due to oscillation modes. It would be predicted, therefore, that no consideration for the performance degradation are necessary in the range of 6-degree amplitude. This could be achieved in extreme motional region for the big 300m-length class vessel hull, yielding the very prospective design merits for the various FPSO projects.

It is necessary to conduct similar testing in the case of tray type columns, if adopted in some fractionation towers. It could be suspected that the tray columns are more sensitive to the degradation, due to the possibility of liquid dripping from the trays/weirs during oscillation modes.

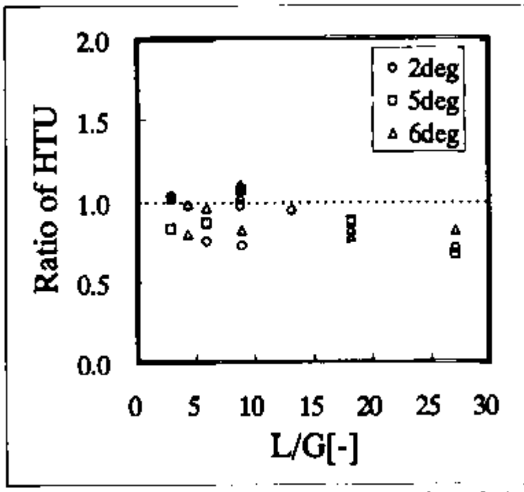

Fig. 7 Performance Influence by Motional Amplitude

DYNAMIC RESPONSE OF FPSO BARGE DUE TO WAVE STIMULUS

It must be key information for the successful LNG FPSO to evaluate quantitatively how much magnitude of acceleration and inclination is imposed to all the equipment on the barge, by the stimulus from ocean waves. The acceleration figures shall be also very much sensitive by the type of the mooring system, and the selection of suitable mooring systems has to be settled at early stage of the study.

Firstly, the numerical analyses were done in time historical response mode, and the results are as follows.

■ Settled Barge Size	295 mL x 60 mB x 25 mD
■ Settled Plant Weight	25,000 t in total
■ Settled Mooring	Single Point Mooring (SPM)
■ Wave Height	2 - 8 m
■ Wave Period	6 - 18 seconds

These calculation results have to be verified and validated by the scaled model testing at IHI's seakeeping and maneuvering tank in the following manners.

■ Scale of Model	Approx. 1/90
■ Wave Configuration	Long crested irregular wave
■ Verification Items	Motional Amplitude
■ Transfer to Plant Design	Accelerations and inclinations in various areas in FPSO

This testing is scheduled to start early January in 1998 and the final results will be due in March, 1998. And it is confidently expected that the results of numerical analyses would be appropriate for the design proceeding of the natural gas liquefaction plant.

CONCLUSIONS

It is confirmed that the LNG FPSO based on the SPB tank system is justified to exploit small and medium size gas fields in offshore which seem to be uneconomic in the past, by the following reasons.

1) The return on investment would be further better than conventional onshore plants, by considering multi-gas fields for sake of the LNG FPSO mobility.
2) The larger LNG throughput by higher availability and higher turndown ratio by adopting multi-parallel operated LM6000GT turbomachinery with appropriate sparing units.
3) Minimizing plant operation and offloading downtime by advantageous feature of SPB, i.e., no sloshing problem even in the case of middle LNG level.
4) The better safety precaution by the establishment of operational philosophy by various model testing results.
5) The easier mobility by a single complete plant SPB LNG FPSO, without separating flare stack barge for the sake of parallel running machinery concept.

This new type of floating plant system will be applicable for a floating storage and regasification unit (FSRU), floating storage and offloading (FSO) and other floating plants. It has to be emphasized that the SPB tank system offers the safe plot capability by the very flat up-deck, and the excellent maintainability by the flat deck & by the ample, uniform and easily accessible clearance around the tank and hull from its prismatic shape. In addition to use as a floating plant, it is considered for the entire plant to be grounded as Industrial Platform System (IPS) in near seashore sites. This IPS plant has the advantages of enjoying well proven technology controlled quality in a shipyard, therefore, it is particularly attractive in areas where infrastructures are insufficient, and where the construction period must be minimized due to extreme meteorological conditions in near arctic and antarctic regions in winter season.

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The authors would like to acknowledge those customers for providing the useful ideas, and other contributions till this study stage.

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