Optimization Study on Floating Structure and Risers Design for a 100 MW-Net Ocean Thermal Energy Conversion (OTEC) Power Plant

Ristiyanto Adiputra [#1], Tomoaki Utsunomiya[#2]

[#]*Marine System Engineering, Kyushu University*
Fukuoka 819-0395, Japan

[1]3TE17262M@s.kyushu-u.ac.jp

[2]utsunomiya@ nams.kyushu-u.ac.jp

***Abstract*— This paper presents a design procedure based on optimization to contrive a floating structure for a commercial scale of OTEC power plant. In the aim to get a safe yet economical floating structure, a commercial oil tanker ship was converted as the plantship. The process was started by defining independent variables, constraints and fix parameters. The independent variables included the velocity of seawater transport and type of oil tanker ship. The next step was breaking down the fix parameters which were kept constant during the iteration process. These parameters were about the general requirements and the necessary equipment to produce 100 MW-net power output. Some constraints were also introduced as permissible borders to determine whether the particular case was acceptable or not. The constraints included the constraint due to provided space, allowed weight, net power output and fluid phenomena on the riser. During the iteration process, a spiral model was developed as analysis guideline. Based on the result of the optimization, it could be concluded that the typical Suez-max oil tanker ship was the best option and the most optimum seawater transport velocity was 3 m/s. Finally, the general arrangements and the base layout design were also conceptualized in this paper.**

***Keywords*— Ocean Thermal Energy Conversion (OTEC), plantship design, Cold water riser, Critical velocity.**

I. INTRODUCTION

Ocean thermal energy conversion (OTEC) is a renewable energy resource which employs the temperature difference between surface and subsurface of the ocean to produce the electricity. The endowment of its utilization is not only about sustainability of green energy supply, but also providing solutions for fresh water deficit, healthy agricultural products, hydrogen production, etc [1].

In essence, an OTEC system consists of condenser, evaporator, turbine generator and working fluid with low boiling temperature [1]. The OTEC schematic system is shown in Fig. 1. The warm seawater passes through an evaporator to vaporize the working fluid, in this case ammonia (1). The ammonia vapor is driven into turbine and rotates the generator to produce the electricity (2). The lower pressure vapor passes through condenser and return to a liquid form after being chilled by cold water from substantial depth (3). The liquid ammonia is pumped back to the evaporator again to repeat the cycle.

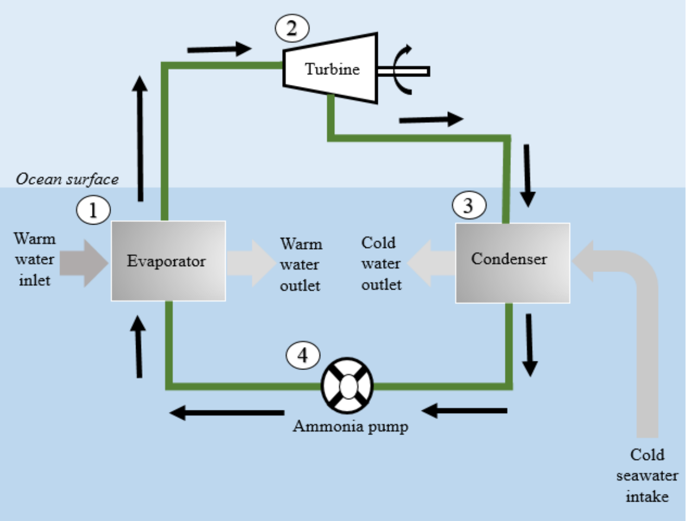

Fig. 1 Schematic OTEC process

The system itself is simple yet the development gets stuck on the pilot projects. The barriers of the commercial development are the lack of knowledge concerning the way to increase its efficiency and the necessity of big capital investment, especially to build the floating structure. The novelity of this structure is the installation of the suspended riser conveying fluid to transport the cold water from around deep water of 1000 m.

From this preliminary study, there are four main results: (1) The most reliable vessel to be converted including its main dimensions and displacement. (2) Using closed-cycle of heat transfer with NH3 as its working fluid, the type, size, capacity, and the required volumetric space of evaporator, condenser and turbine-generator can be decided. (3) Considering the required flowrate and statistic load balance, the scantlings and the material of all sea water pipes can be determined. (4) Finally, the layout of the plantship can be designed.

II. METHOD

The design of the floating structure and the risers must be considered in coupled way. This makes the project very large with complex requirements. If one of the system fails, the global failure might be triggered. In order to overcome this matter, a spiral model was proposed as an analysis guideline as shown in Fig. 2. This paper covers the preliminary steps which embodies the first three steps of the whole spiral.

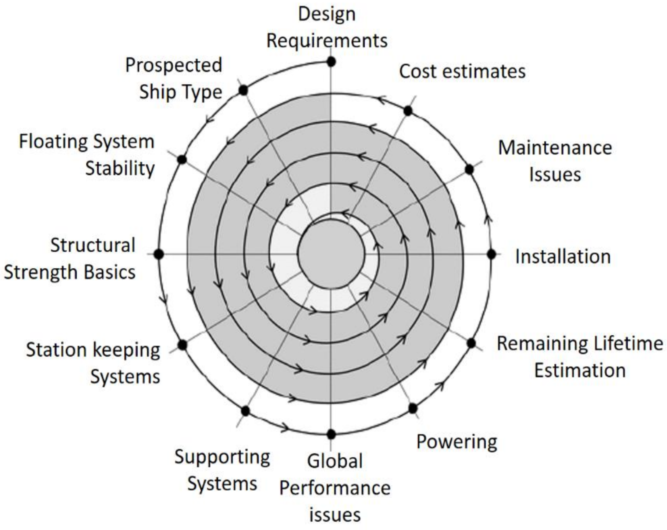

Fig. 2 Spiral model for analysis guideline

After the process completes one cycle, the analysis continues from the start point again and stops after reaching the desired condition. By employing this method, an incremental refinement can be developed through each iteration. This process is applied to all cases to get its optimum configurations. Considering the result of the iteration, the case which fulfils the constraints will be concluded as the most optimum one.

There were three main parameters imposed in the iteration process. Variables which were varied during the iterations named independent variables, Fix variables indicating constant parameters which didn't change during the optimization, and constraints which were introduced as limitations.

III. OPTIMIZATION PROCESS

A. *Independent Variables*

There were two main independent variables in this analysis. The first was the type of oil tanker ship to be converted and the second was the velocity of seawater transport. The general dimension was adapted based on `typical` dimension for particular type of oil-tanker ship. The value was in a range. Thus in the iteration process, the selected value could be any number as far still in the range. Table 1 shows the oil tanker specifications. In the case of the velocity of seawater transport, the variable was built by varying the velocity from 2 m/s to 6 m/s with an increment of 0.5 m/s.

TABLE I
TYPICAL DIMENSION OF OIL TANKER SHIP [2,3]

Type	L (m)	B (m)	T (m)	Displacement (ton)
Aframax	245	34	16	111670
Suezmax	285	50	23	274650
VLCC	330	55	28	425870
ULCC	415	63	32	701100

The type of the floating structure will affect the total buoyancy and the total space. The velocity of seawater transport will affect to the water-hammer phenomena, abrasion of the riser and the required dimension of the riser to provide certain amount of seawater debit.

B. *Fix Required Parameters*

These parameters included location of the site, required flowrate, heat exchanger and the scantlings of the risers.

1) Location of the Site: In this study, the location of the site is in Indonesia. Several researchers have been studying the potential of OTEC development in all around the country. The latest research done by Jaswar Koto et al states several locations which are the most reliable and suitable for OTEC power plant as shown in Fig. 3 [4]. Region A is Siberut island located in West Sumatra, region B is North Sulawesi, Region C is Morotai island and region D is West Papua. The surface temperature and 700 m of water depth temperature are listed in Table 2.

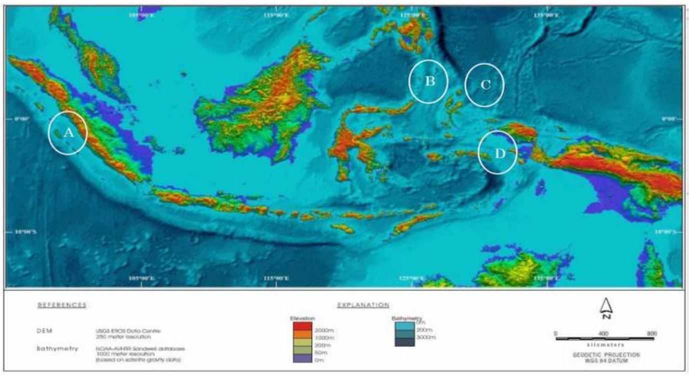

Fig. 3 Bathymetry map of Indonesia [4]

TABLE II
CHARACTERISTIC TEMPERATURE OF THE PROSPECTIVE SITES [4]

Location	Surface temperature (ºC)	Temperature at 700 m of depth water (ºC)
Siberut island	29	8.2
Sulawesi	29	6
Morotai sea	29	6
West Papua	29	7

For the analysis, Siberut island was chosen considering its location which relatively has calm sea state condition compared with the east part of Indonesia. The temperature difference between surface water and subsurface water in Siberut island has hit 20ºC in the water depth 700m. However, to overcome the uncertainties and energy losses during the system, the cold water riser will be lengthened up to 800m of water depth.

2) Required flow rate: The system is to utilize working fluid with low boiling temperature operating between cold temperature and hot temperature. The working fluid receives the heat from surface water and then expands into gas form. It drives the turbine and produces electricity using a generator. After that, the working fluid will be cooled down using cold water pumped from substantial depth [5]. The correlating equation between net power output and the required flowrate of cold water modelled by Nihous [6] was adopted as

$$P_n = \frac{\theta_{cw}\rho c\varepsilon_{tg}}{8T_h}\left\{\frac{3\gamma}{2(1+\gamma)}\Delta T^2 - 0.18\Delta T^2{}_{design} - 0.12(\gamma/2)^{2.75}\Delta T^2{}_{design}\right\} \qquad (1)$$

ΔT is the temperature difference between warm and cold water in the real condition, ΔT_{design} is the temperature difference in the design. Because the temperature gradient in the tropical area is relatively steady, ΔT_{design} can be assumed as equal to ΔT. T is surface water temperature, ε_{tg} is the turbine generator efficiency, θ_{cw} is the cold water flow rate, γ is comparison between warm water flowrate and cold water flowrate, ρ is the density of the water, c is heat capacity at constant pressure.

Inputting the value of:

$\gamma = 2$ $\qquad T \cong 300$ K $\qquad c = 4$ kJ/kg K

$\rho = 1025$ kg/m^3 $\qquad \Delta T \cong 20$ K $\qquad \varepsilon_{tg} = 0.93$ [7]

into Eq. (1) as basis evaluation of OTEC resources, it corresponds to a total deep water flowrate intensity of 2.25 m^3/s per MW (net) at design condition γ equal to 2. In this research, the addressed net power output is 100 MW.

Thus, the required flow rate will be

$$\theta_{cw} = 100 \times 2.25 = 225 \text{ m}^3/\text{s} \qquad (2)$$

$$\theta_{ww} = \gamma \times 225 = 450 \text{ m}^3/\text{s} \qquad (3)$$

As comparison, Vega (2012) [8] has estimated the size of the cold water pipe for 100 MW OTEC power plant and obtained the same result with this present study.

3) Thickness of Cold Water Pipe and Warm Water Pipe: The system is to utilize working fluid with low boiling temperature Thickness of cold water pipe (CWP) and warm water pipe (WWP). Initially the thickness was estimated by hand calculation based on the approximation formula for riser of oil and gas exploration [9]. The features of both cold and warm water pipe were adopted here as reported in [10]. The CWP and WWP are made of a Fiberglass reinforced plastic sandwich construction, i.e. two fiberglass layers separated by a layer syntactic foam. The material properties of FRP are: The laminate density is 4125 kg/m^3; the density of syntactic foam is 1015 kg/m^3; Modulus of elasticity is 13776 MPa; the flexural rigidity is 2.89x10^{11} Nm^2. The results of the estimation are shown in Table 3.

4) Heat Exchanger and Turbine Generator. The type of heat exchanger used in this study is compact plane-fin heat exchanger which developed by Argonne National Laboratory, USA [11]. The core dimensions of this compact plane-fin heat exchangers are 6.1 m (L) x 1.2 m (B) x 4.6 m (H). The estimations consider that four cores are required for a 4 MW-gross NH_3 [11,12]. Thus, to reach 140 MW-gross NH_3, 36 evaporator submodules must be integrated. Including flanges, ducting, piping, the overall dimensions will require a volumetric space of 136 m (L) x 46 m (B) x 16 m (H). These dimensions are also applicable to the 140 MW-gross NH_3 condenser module.

The lists of turbine-generator which have a good performance are available from well-established manufacturer [12]. The maximum size available is at about 15 MW-gross with a volumetric space required 12 m (L) x 8 m (B) x 5 m (H). Considering the capacity of single turbine-generator, the systems at least must employ 9 units of turbine-generator. The total required space will be 30 m (L) x 48 m (B) x 8 m (H) including the lube-oil-skid. The summary of the volumetric space requirements for heat exchangers and turbine generators are listed in Table 4. Then, the weight for each component must be considered into the calculation of weight balance. Table 5 shows the weight of the main machinery.

TABLE IV
VOLUMETRIC SPACE OF HEAT EXCHANGER AND GENERATOR

Unit	Parameter (L x W x H)
Evaporator	45 x 46 x 16 (m)
Turbines	30 x 48 x 8 (m)
Condenser	45 x 46 x 16 (m)

TABLE III
MAIN DIMENSION OF THE ATTACHED RISERS

Pipe	Length (m)	Average thickness (cm)	Thickness of the fiberglass layer (cm)	Thickness of the syntactic foam(cm)
Cold water inlet	800	16	2	14
Cold water outlet	40	8	0.8	7.2
Warm water inlet	20	6	0.5	5.5
Warm water outlet	40	8	0.8	7.2

TABLE V
WEIGHT OF MAIN ENGINE FOR OTEC SYSTEM

Unit	Weight/item (ton)	Total weight (ton)
Turbine (9 turbines)	80	720
Evaporator (9 submodules)	2160	19440
Condenser (9 submodules)	2160	19440

C. Constraints

There were some limitations in the iteration process to decide the type of oil tanker and seawater transport velocity which were constraint due to area of seawater tank, constraint due to required buoyancy, constraint due to net power output, and constraint due to abrasion phenomena on the pipe.

1) Constraint due to required buoyancy: In this analysis, the weight of each sub systems were broken down to strengthen the estimation as follow

a. Weight of riser, steel and residual weight

The method for estimating the weight of the steel and the residual weigh was carried out referring the book "Practical ship design chapter 4/4.2.4" by D.G.M. Watson [13]. The residual weight covered several items such as supplementary engines (generator set, pumps, electricity equipment, propulsion machinery, positioning control engine), fresh water supply and sewage tank, derrick, crew and provision. In this preliminary study, the weight of the residual weight was assumed to be around 5% as typical very large oil tanker [14]. The weight of the riser was calculated considering the material properties and its scantling as shown in table 3.

b. Weight of fluid on board

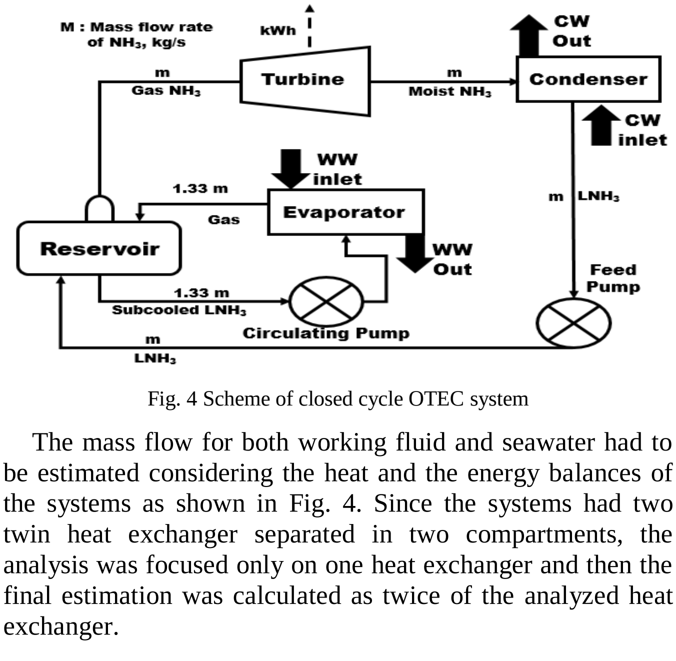

Fig. 4 Scheme of closed cycle OTEC system

The mass flow for both working fluid and seawater had to be estimated considering the heat and the energy balances of the systems as shown in Fig. 4. Since the systems had two twin heat exchanger separated in two compartments, the analysis was focused only on one heat exchanger and then the final estimation was calculated as twice of the analyzed heat exchanger.

2) Constraint due to net power output. The step by step calculation procedure to estimate the required pump power can be written as [15]

$$P_h(W) = q\rho gh / \eta \tag{4}$$

Where

P_h : hydraulic power (kW)
q : flowrate capacity (m^3/s)
ρ : density of transported fluid
g : gravity acceleration (m/s^2)
h : total head of the pump (m)
η : pump efficiency

The differential head or the required pump head is calculated as follow

$$h = h_1 + h_2 + h_3 \tag{5}$$

Where

h_1 : The distance between pump and the water surface in the tank. This value depends on the placement of the pump.
h_2 : The depth of water in the tank transported in one second. This is calculated as debit per area of water tank
h_3 : head loss due to density change and friction. Head loss due to density change is assumed to be 1 m in cold water inlet and 0.01 m in the case of cold water outlet, warm water inlet and warm water outlet.

The head loss due to friction was calculated based on Hazen William formula [16] as

$$h_f(l/100) = \frac{608704451}{d_{mm}^{4.8655}} \times \left(\frac{Q_{L/\min}}{C}\right)^{1.85} \tag{6}$$

Where

h_f : friction head loss in meter per 100 m of the pipe
C : roughness coefficient, 150 for FRP [17]
d : diameter of the pipe in meter
$Q_{L/\min}$: flow rate in liter/minute

3) Constraint due to abrasion phenomena on the risers. Water from deep ocean is a rich-mineral water with high concentrate minerals as well as sand particles. Conveying this type of water may trigger material degradation and gradually affect to the piping integrity. Thus the abrasion and erosive wear in the piping system must be considered carefully. The equation to calculate the erosive wear was adopted from DNV recommended practice RP O501 [12] for smooth and straight pipes as

$$E_l = \frac{2.5 \times 10^{-5} \times u^{2.6} \times m_p \times REF}{d^2} \quad (5)$$

Where

E_l : erosive rate per year (mm/year)

u : velocity of seawater transport (m/s)

d : diameter of the pipe (m)

m_p : mass flow of sandy particles (kg/s).

REF : Relative Erosion Factor. It indicates volume loss of certain material/ volume loss of C-steel grade typical for piping system.

Setting up the life time of the riser as 25 years, the calculation showed that the critical velocity of seawater transport is 3.7 m/s. In this case, 3.5 m/s of seawater transport was chosen as upper limit to bear the uncertainties.

4) Constraint due to area of seawater tank. This constraint is due to required work for pumping system. If the seawater tank doesn't have an adequate area in the certain level of seawater flow rate, the depth of the water transported in one second, h_2 will be so high. This will affect the total pump head in Eq. (5).

Based on the initial assessment that the net power output should not be less than 70% of gross power [6], the total area of the cold water tank was at least 50 times the area of cold water pipe, but in the case of warm water tank, the area should be more than 40 times the area of warm water pipe. The result in the terms of minimum length of the whole plantship is shown in table 8.

IV. Optimization Results

The results were carried out for each constraint. Table 6 shows the total required weight by summing up the weight of the fluid on board and the light weigh. Table 7 indicates how the velocity of water transport affected the required pump work which was then used to calculate the net energy product. Table 8 shows the total required length.

Initially, there were four types of oil tanker ship which were analyzed in this study. In the early stage of iteration process, it could be easily judged that the smallest type was not suitable for 100 MW-net power output. Here onwards, this type of oil tankers was excluded in the iteration to minimize the analysis effort.

Comparing constrain-based results as shown in Table 6, 7, 8 and the provided capacity for each type of oil tanker ship, the decision could be made whether the particular case was rejected, recommended, or even over design. If the total required parameter was higher than the provided capacity, the configuration should be rejected. In the other hand, if the provided capacity was much bigger than the necessary one, it implied an over design condition. The recommended one was when the difference between the provided and the required capacity is around 0-5% of the required capacity.

TABLE VI
Total Required Weight

velocity of seawater (m/s)	**Total fix weight (ton)** **Suez max**	**VLCC**	**ULCC**
2.00	285340	345270	511570
2.50	272090	332220	499080
3.00	263230	323520	490750
3.50	256900	317300	484800
4.00	252150	312640	480340
4.50	248440	309010	476870
5.00	245480	306110	474090
5.50	243050	303740	471820
6.00	241020	301760	469920

TABLE VII
Net Power Output Calculation

Velocity of fluid (m/s)	**Gross energy (MW)**	**Pump work (MW)**	**Additional equipment (MW)**	**Net energy (MW)**
2	143	26.42	14.30	102.16
2.5	143	26.78	14.30	101.79
3	143	27.22	14.30	101.35
3.5	143	27.73	14.30	100.84
4	143	28.32	14.30	100.25
4.5	143	28.99	14.30	99.58
5	143	29.76	14.30	98.82
5.5	143	30.61	14.30	97.96
6	143	31.56	14.30	97.01

TABLE VIII
Total Required Length

velocity of seawater (m/s)	**Total length (m)** **Suez max**	**VLCC**	**ULCC**
2.00	367.50	340.91	307.14
2.50	309.00	287.73	260.71
3.00	270.00	252.27	229.76
3.50	242.14	226.95	207.65
4.00	221.25	207.95	191.07
4.50	205.00	193.18	178.17
5.00	192.00	181.36	167.86
5.50	181.36	171.69	159.42
6.00	172.50	163.64	152.38

TABLE IX
OPTIMIZATION RESULT

Ship type	Velocity of seawater	Constraint due to area of seawater tank	Constraint due to required buoyancy	Constraint due to net power output	Abrasion effect	Conclusion
Suez- max	2	Rejected	Rejected	Accepted	Safe	Rejected
	2.5	Rejected	Recommended	Accepted	Safe	Rejected
	3	**Recommended**	**Recommended**	**Accepted**	**Moderate**	**Recommended**
	3.5	Over design	Recommended	Accepted	Critical	Critical
	4	Over design	Over design	Accepted	Fail	Rejected
	4.5	Over design	Over design	Rejected	Fail	Rejected
	5	Over design	Over design	Rejected	Fail	Rejected
	5.5	Over design	Over design	Rejected	Fail	Rejected
	6	Over design	Over design	Rejected	Fail	Rejected
VLCC	2	Rejected	Over design	Accepted	Safe	Rejected
	2.5	Over design	Over design	Accepted	Safe	Over design
	3	Over design	Over design	Accepted	Moderate	Over design
	3.5	Over design	Over design	Accepted	Critical	Critical
	4	Over design	Over design	Accepted	Fail	Rejected
	4.5	Over design	Over design	Rejected	Fail	Rejected
	5	Over design	Over design	Rejected	Fail	Rejected
	5.5	Over design	Over design	Rejected	Fail	Rejected
	6	Over design	Over design	Rejected	Fail	Rejected
ULCC	2	Over design	Over design	Accepted	Safe	Over design
	2.5	Over design	Over design	Accepted	Safe	Over design
	3	Over design	Over design	Accepted	Moderate	Over design
	3.5	Over design	Over design	Accepted	Critical	Over design
	4	Over design	Over design	Accepted	Fail	Rejected
	4.5	Over design	Over design	Rejected	Fail	Rejected
	5	Over design	Over design	Rejected	Fail	Rejected
	5.5	Over design	Over design	Rejected	Fail	Rejected
	6	Over design	Over design	Rejected	Fail	Rejected

Because a plantship for OTEC power plant is still an undeveloped structure, the approach to determine some parameters such us the weight of steel, residual weight and the weight for complementary appliances were just simply referred to the references for FPSO application. In the future, more accurate and more detailed analysis will be conducted in order to ensure that all estimations are close enough with the real condition. However, a permissible tolerance of 5% had been introduced during the iteration process, this was to make spaces for the uncertainties and possibility for further modifications.

Table 9 shows the result of the optimization. From the table, it can be concluded that Suez-max oil tanker ship with seawater transport of 3 m/s is the most recommended one.

There is a big aberration between the characteristic of oil tanker ship and the floating structure for OTEC power plant. The load of oil tanker ship is oil which has density lower than seawater with very low permeability. In the case of a plantship for OTEC power plant, the load is mainly seawater and the working fluid which has density far below seawater. This make the ratio between total volumetric space per dead weight tonnage of oil tanker ship is lower than a planthip for OTEC power plant. This indicates that the required buoyancy for the same required volumetric space for the OTEC floating structure is lower than oil tanker ship. Thus, in this analysis, the typical dimension of Suez-max oil tanker ship listed in table 1 was used except the draft that changed from 23m to 16m.

The draft adjustment decreases the draft per breadth ratio around 30% causing the possibility of stability problem. In the further analysis, the statistical stability will be considered specifically along with the ballast placement decision to minimize the trim of the plantship.

The draft adjustment decreases the draft per breadth ratio around 30% causing the possibility of stability problem. In the further analysis, the statistical stability will be considered specifically along with the ballast placement decision to minimize the trim of the plantship.

V. GENERAL ARRANGEMENT OF THE PLANTSHIP

Fig. 5 shows the base layout design of 100 MW OTEC power plant. It will be built up in the shipyard, then floated and towed to the distance of 10 km from Mentawai coastal line. Its overall displacement is about 220000 tonnes.

The outline of the plantship was drawn referring to a book entitled `Principle of Naval Architecture`. Even though it may differ with the existing oil tanker ship, the tendency of the outline still the same as it was design considering tight parameters for the real usage.

To arrange and do the arrangement and compartmentation, initially the center of buoyancy was estimated and then the weight of equipment as well as the seawater tank were distributed in equal manner. The electricity production was divided into two compartments with same specifications. There were in front of center of buoyancy and behind center of buoyancy. Because the total weight was mainly due to seawater storage, the location of the seawater tank would be the center of consideration. Among the other seawater tank, the cold water storage was the biggest one. Thus, the cold water tank was placed at the center of buoyancy along with the cold water riser. The main aim was to make the longitudinal center of gravity as close as possible to the center of buoyancy to minimize trim of the plantship. The placement of the cold water pipe at the center of buoyancy was also to decrease the effect of the dynamic motion of the riser to the floating structure. Additionally, the other risers were also suspended on the floating structure with the same distance to the center buoyancy to make the weight moment neglect each other.

The pumping systems for seawater transport was located directly above the seawater storage and the pump for working fluid was located at the port and starboard beside the turbo-generator to minimize the pump work. The turbo-generator block was located above the heat exchanger to shortened the distance of the ammonia vapor path from the heat exchanger to the turbo generator to increase the efficiency during the OTEC cycle.

The fore part of the plantship was allocated for the equipment of positioning control such us anchors, chain locker, etc. The after part of the plantship was used for control activity space including control room for position monitoring, OTEC control, etc. The hotel for crew and other daily activities were placed on the superstructure. The first layer was for common activity and the next layer was for private rooms.

Beneath seawater tank, there is a space for riser handling equipment with height of inner bottom of 5m. This particular part needs more consideration and detail to ensure that the riser handling integrity has adequate strength to sustain both internal and external load.

During the iteration process, the location of ballast water was varied either at fore peak tank, after peak tank, double bottom tank or double hull tank. Finally, to stabilize both buoyancy estimation and longitudinal center of gravity calculation, the ballast water was placed at the fore peak.

VI. CONCLUSION AND FUTURE WORK

Floating structure from oil tanker conversion for 100 MW-net OTEC power plant has been conceptualized. This plantship will be deployed in the west part of Indonesia ocean. Initially, the iteration process was done to decide the type of oil tanker ship to be converted and to determine the velocity of seawater transport. The optimization process was conducted by varying the independent variables with several constraints as limitation and guided using spiral. From the analysis, it can be concluded that Suez-max type oil tanker with seawater transport of 3 m/s is the most recommended. The summarize of the main dimension of the plantship is shown in Table 10.

TABLE X
MAIN DIMENSIONS OF THE PLANTSHIP

Parameter	**Value**
Type	Suez-Max
Lpp (m)	275
LoA (m)	285
Breadth (m)	50
Height (m)	30
Draft (m)	17
Cb	0.945
Tonnage (ton)	200000

The future work will be about an analysis of riser design including:

1. Dynamic analysis: must be able to withstand collapsing loads created by suction.
2. Hang-off and end-mounted riser analysis
3. Top joint connection
4. Stiffening method for the riser design
5. VIV analysis to avoid fatigue damage.

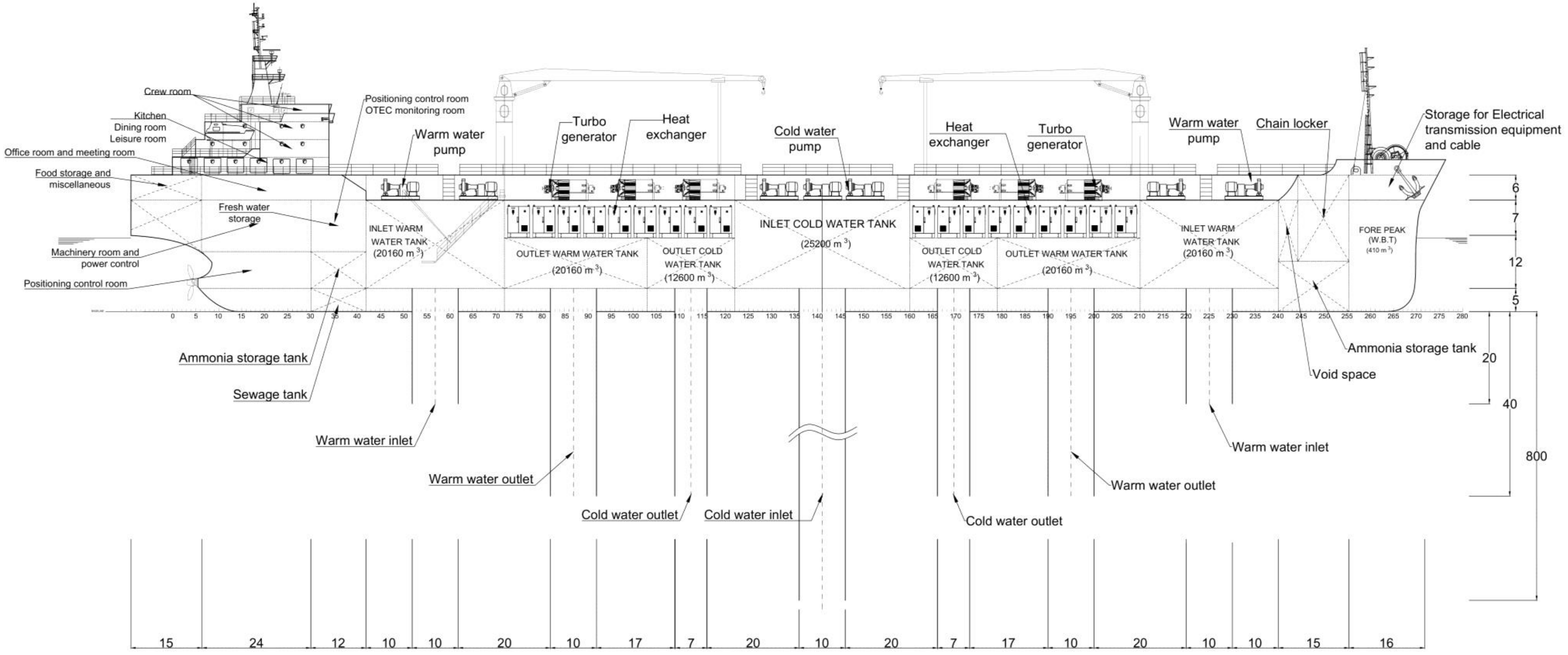

Fig. 5 Layout design of 100 mw-net OTEC plantship

REFERENCES

[1] Syamsuddin, Mega and Attamimi, Adli. "OTEC Potential in the Indonesian Seas." *Energy Procedia* vol. 65, pp. 215 – 222, 2015.

[2] Papanikolaou, Apostolos. *Ship Design Methodologies of preliminary design.* Netherlands: Springer Science+Business Media, 2014.

[3] Canadian Gateway Additional Evidence. *"TERMPOL Surveys and Studies."* Northern Gateway Additional Evidence, Canada, Tech. Rep. No. A29571 Section 3.9, 2010.

[4] Koto, Jaswar. "Potential of 100 KW Ocean Thermal Energy Convention in Indonesia*." Proceeding of JASNAOE* pp. 763-767, May 2017.

[5] Vega, Luis. "First Generation 50 MW OTEC Plantship for the Production of Electricity and Desalinated." *Proceeding of Offshore Technology Conference*. OTC 20957, pp.1-17, May 2010.

[6] Nihous, Gerard. "A Preliminary Assessment of Ocean Thermal Energy Conversion Resources." *ASME Journal of Energy Resources Technology* vol.129, pp.247-256, 2007

[7] Uehara, Haruo and Ikegami, Yasuyuki. "Optimization of a Closed-Cycle OTEC System." *ASME Journal of Solar Energy Engineering* vol.112, pp.10-17, 1990

[8] Vega, Luis. "Ocean Thermal Energy Conversion." *Encyclopedia of Sustainability Science and Technology, Springer* vol.6, pp. 7296-7328, 2012.

[9] Yong, Bai. *Pipelines and Riser Vol.3*. England: Elsevier Science Ltd., 2001.

[10] Nihous, Gerard and Vega, Luis. "Design of a 100 MW OTEC-Hydrogen Plntship." *Journal of Marine Structure* vol.6, pp. 207-221, 1993.

[11] Energy systems division. "Ocean Thermal Plantships for production of Ammonia as the Hydrogen carrier." Argonne National Laboratory, Tech. Rep. No. ANL/ESD/09-6., 2009.

[12] Engels, Walter and Zahibian, Farshid. "Principle and Preliminary Calculation of Ocean Thermal Energy Conversion." *Proceeding of American Society for engineering Education* 2014 Zone 1, pp.1-5, April 2014.

[13] Watson, D.G.M. *Practical Ship Design*. England: Elsevier Science Ltd., 2002.

[14] Schneekluth, H. *Ship Design for Efficiency and Economy* England: Elsevier Science Ltd., 1998.

[15] O. Kvernvold and R. Sandberg. "Production Rate Limits in Two-phase Flow Systems – Sand Erosion in Piping Systems.", Technical Report No. 93-3252. DNV, 1993.

[16] Travis, Q and Mays, L. "Relationship between Hazen-William and Colebrook-White roughness value." *Journal of hydroulic Engineering* vol.133, pp. 1270-1273, 2007.

[17] Nicholas, Cheremisinoff. and Paul, *Cheremisinoff. Fiberglass Reinforced Plastic: Manufacturing Techniques and Applications*. Noyes Publications, U.S.A ,1995.