REPORT OF TRAINING ON

SATREPS-OTEC PROJECT

'The 1st on the site training of OTEC and DSW applications'

Imari, Saga and Kumejima, Okinawa, Japan 2-10 December 2019

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SATREPS PROJECT
Ocean Thermal Energy Conversion

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This report presents the training activities and the results from JICA Counterpart Training in Japan during the period 2-10 December 2019. This short-term training, called 'the 1st On-Site Training of OTEC and DSW Applications', was supported by JICA SATREPS-OTEC Project: Development of Advanced Hybrid-Ocean Thermal Energy Conversion (OTEC) Technology for Low Carbon Society and Sustainable Energy System: First Experimental OTEC Plant of Malaysia.

This Report would also greatly help Malaysia to realise its total potential in harnessing not only its ocean thermal energy resources but also the full utilization of the cold deep sea water off the eventual operating ocean thermal energy conversion (OTEC) plants, especially those nearest to the coastlines of the States of Sabah and Sarawak.

OTEC Technology has been recognized, not only among the 21 most impactful and emerging technologies in this 21st Century, but it is perhaps the only advanced technology that could easily fulfill all the 17 Sustainable Development Goals of the United Nations. Its accomplishment has already been demonstrated very well on the Island of Kumejima, Okinawa, Japan, where 2x50 kW of OTEC green-power has been generated to support various spin-off industries on this Island that utilize the cold deep sea water that is rich in nutrients for the culture of high value marine produce the like of "umi budou", oysters, prawns, fugu-fish, or even abalone, and that of marine products including mineral water, cosmetics and other beauty products. The applications of various OTEC-related technologies have essentially transformed the economy of Kumejima from the traditional sugar and pineapple growing into totally the advanced "blue economy".

It is the aspiration of Malaysia not only to emulate the successes of Japan in developing the core engineering of the ocean thermal energy conversion plant and the OTEC-spinoff industries, but also to undertake joint R&D and further innovation in order to advance the current state of knowledge, systems, and practices, including the prospects of producing green Hydrogen from at least 26,000 MW of OTEC potential in Malaysia. Thus, any bilateral as well regional and international programmes that would promote close co-operation, collaboration, and partnership would be very much welcome.

It is also very important for Japan to work closely with the tropical countries the like of Malaysia. Being located along the Equator, the potential of OTEC could be harnessed 24/7 and throughout the year. Malaysia could be the focus of future OTEC development not only in the South East Asia and but also throughout the Asia-Pacific region.

Global partnership is also important in realizing the fact that OTEC Technology could help address the Climate Change challenges and offset carbon dioxide emissions, that is, 8,000 tonnes of CO2 per MW of OTEC power generated. In other words, the generation of 3825 GW of OTEC throughout the tropical world could offset the total global CO2 emissions in 2020 of 30.6 Giga tonnes.

In short, go for OTEC, and move toward a sustainable future.

FORWARD SATREPS-OTEC RESEARCH DIRECTOR

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Malaysia is one of the world's leading countries with high ocean thermal energy conversion (OTEC) potential. In addition, UTM has the leading OTEC research and development team.

Japan has been researching OTEC for over 45 years and has the world's most advanced research facilities.

The purpose of this SATREPS project is for Malaysia and Japan to promote the social implementation of OTEC and human resource development for the purpose of contributing to the achievement of the SDGs.

Human resource development related to OTEC is the most important portion of this SATREPS project. This human resource development is not only general lectures.

The human resource development will be carried out at the Institute of Ocean Energy, Saga University in Imari City, Saga Prefecture and the Okinawa Ocean Thermal Energy Conversion Facility in Kumejima, Okinawa Prefecture. This program is the world's first international human resource development program that actually uses an operational OTEC Facility.

First, participants will actually operate the world's most advanced research apparatus at Saga University, acquire data, analyze the data, and gain a deeper understanding of the reality of OTEC.

Next, it will use the 100kW ocean thermal energy conversion plant in Kumejima, Okinawa Prefecture, which has been operational since 2013 and the only operational plant of its type in the world. They can actually operate an OTEC plant and analyze its data to gain a better understanding of real-world OTEC plant operations.

This Kumejima Island in Okinawa Prefecture is an island with a population of about 7,000 people, but the "Kumejima Model" that uses OTEC and deep sea water application is most world-famous. Kumejima has actually grown a deep sea water utilization industry that surpasses the sugar cane industry, which was a major industry 20 years before the deep sea water intake began, more than 2.5 times. In particular, there are various products such as prawns, sea grapes, cosmetics, water, salt, and vegetables. The production of prawns and sea grapes is the highest in Japan.

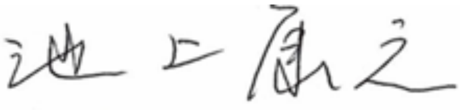
This project is aiming to further develop this "Kumejima Model" and construct a "Malaysia Model" that combines global OTEC and deep sea water utilization suitable for Malaysia.

Therefore, in this human resource development program, we visit Kumejima to consider application to the "Malaysia Model", and held lectures and group discussions to build the "Malaysia Model." Groups were formed consisting of 4-5 people, and there was a hot discussion about what aspects of each group's preliminary "Malaysia model" are suitable for Malaysia and what should be done to construct it. We also think it is necessary to develop and realize the results of this project.

The "Malaysia model" proposed by the participants was completed with a higher level and degree of accuracy than we imagined. When reading this report, you can feel the high level.

Some of the ideas of some "Malaysian Models" suggested by the participants will be realized in the near future. In addition, I think we must develop and realize the results of this project.

To achieve this, we need a deep understanding of OTEC and a aspiration for achieving the SDGs. I would hope that the participants will promote their international leadership in realizing the "Malaysia model" in Malaysia and around the world with this experience and high aspirations in this program.



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TRAINING REPORT

TRAINING REPORT

REPORT ON THE 1ST ON THE SITE TRAINING OF OTEC AND DSW APPLICATIONS

PROJECT TITLE

Development of Advanced Hybrid Ocean Thermal Energy Conversion (OTEC) Technology for Low Carbon Society and Sustainable Energy System: First Experimental OTEC Plant of Malaysia

Name: **Assistant Prof. Dr.YASUNAGA Takeshi**
Ts. Dr. Sathiabama T. Thirugnana
Title: **Project Manager**
Submission Date: **14 April 2020**

1. PURPOSE AND METHOD

1-1 Purpose of the training

The training program "On the site training of OTEC and DSW applications" is a knowledge transfer program based on experience of research on Institute of Ocean Energy, Saga University (IOES), Japan and deep seawater industries in Japan, and is aimed for construction of the Malaysia Model for low carbon and sustainable society in Malaysia, South East Asia (SEA) and around the world.

In this program, the participants will widely learn about topics as follows:

(i) OTEC and its basic knowledge, OTEC facility maintenance & amp, operation as well as analysis of the data using OTEC testing plants in IOES Imari satellite and Okinawa prefectural pilot plant in Kumejima Deep Seawater Research Centre

(ii) OTEC and its spin-off industries, present condition of DSW application in Kumejima, Japan

1-2 Method of the training

For human capacity building and capital development in OTEC Technology, IOES, Japan organized the training on OTEC to transfer knowledge and know-how of research in Saga University and experience on Kumejima model in IOES Imari satellite in Imari city and Okinawa Prefectural Deep-seawater Research Centre (OPDRC) in Kumejima town, respectively. The training was conducted using the facilities on site in IOES OTEC test rigs and OPDRC OTEC demonstration plant. Besides OTEC application, general thermodynamics were covered and training was done in IOES Imari.

2. SCHEDULE AND PARTICIPANTS (AS ATTACHMENT)

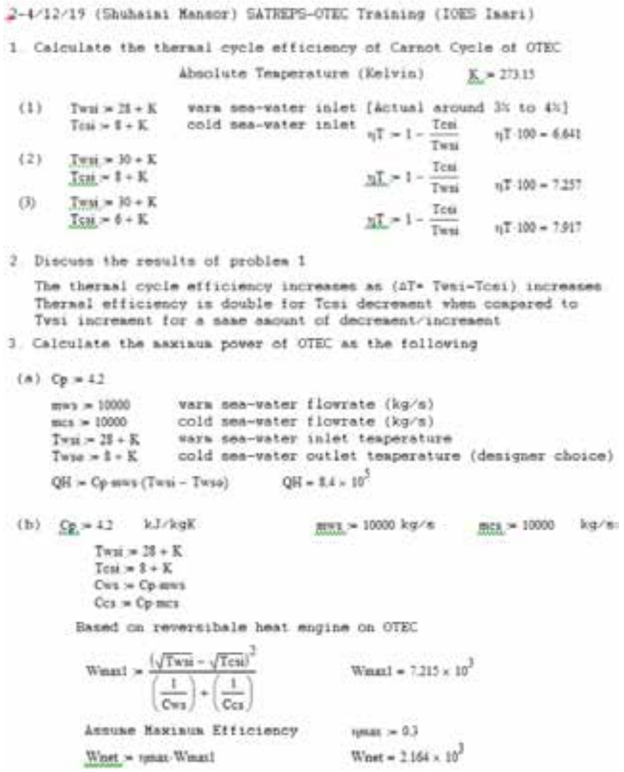
The entire training was held from 2nd till 10th December 2019 in two places. The first one was in IOES satellite in Imari to learn the basics of thermodynamics and OTEC application, and the next was OTEC test facility operation, analysis and management from 2nd till 4th December 2019. Then, all participants visited Kumejima for the training of OTEC pilot plant management and to learn about the deep seawater (DSW) applications in Kumejima to consider the Malaysian model for this project. Please refer to Annex I for more details of schedule and Annex II & III for students and academics details who participated in this SATREPS OTEC training. The planned timeframe and training content was very comprehensive and benefited all participants.

3. BASIC ENGINEERING SKILL TRAINING FOR OTEC AT IOES IMARI SATELLITE

3-1 Thermodynamics (vapor cycle)

The training began with an introduction to Carnot cycle and Rankine cycle theory. The main objective is to give a good understanding of the function of pump, evaporator, turbine and condenser and their individual functions in a complete process/system of vapor cycle, applicable to OTEC system. The explanation of T-S diagram related to thermodynamics vapor cycle and the function of components in OTEC system were conducted thoroughly. The training contents were overwhelming and preferably need to add 1 or 2 more days for the participants to understand thoroughly.

Tutorial of vapor cycle calculation as shown in Figure 3.1 using an experimental data analysis of OTEC system at IOES plant as a case study was a practical approach. Evaluation of thermal efficiency, using the actual case study provided us a good understanding on theoretical and actual physical system of OTEC system.


2-4/12/19 (Shuhaimi Mansor) SATREPS-OTEC Training (IOES Imari)

1. Calculate the thermal cycle efficiency of Carnot Cycle of OTEC

Absolute Temperature (Kelvin) $K := 273.15$

(1) $Twsi := 28 + K$ warm sea-water inlet [Actual around 3% to 4%]
$Tcsi := 8 + K$ cold sea-water inlet $\eta T := 1 - \frac{Tcsi}{Twsi}$ $\eta T \cdot 100 = 6.641$

(2) $Twsi := 30 + K$, $Tcsi := 8 + K$ $\eta T := 1 - \frac{Tcsi}{Twsi}$ $\eta T \cdot 100 = 7.257$

(3) $Twsi := 30 + K$, $Tcsi := 6 + K$ $\eta T := 1 - \frac{Tcsi}{Twsi}$ $\eta T \cdot 100 = 7.917$

2. Discuss the results of problem 1

The thermal cycle efficiency increases as (ΔT= Twsi-Tcsi) increases
Thermal efficiency is double for Tcsi decrement when compared to
Twsi increment for a same amount of decrement/increment

3. Calculate the maximum power of OTEC as the following

(a) $Cp := 4.2$

$mws := 10000$ warm sea-water flowrate (kg/s)
$mcs := 10000$ cold sea-water flowrate (kg/s)
$Twsi := 28 + K$ warm sea-water inlet temperature
$Twso := 8 + K$ cold sea-water outlet temperature (designer choice)
$QH := Cp \cdot mws \cdot (Twsi - Twso)$ $QH = 8.4 \times 10^5$

(b) $Cp := 4.2$ kJ/kgK $mws := 10000$ kg/s $mcs := 10000$ kg/s
$Twsi := 28 + K$
$Tcsi := 8 + K$
$Cws := Cp \cdot mws$
$Ccs := Cp \cdot mcs$

Based on reversibale heat engine on OTEC

$Wmax1 := \frac{(\sqrt{Twsi} - \sqrt{Tcsi})^2}{\left(\frac{1}{Cws}\right) + \left(\frac{1}{Ccs}\right)}$ $Wmax1 = 7.215 \times 10^3$

Assume Maximum Efficiency $\eta max := 0.3$
$Wnet := \eta max \cdot Wmax1$ $Wnet = 2.164 \times 10^3$

Figure 3.1: Thermal cycle efficiency

In the next exercise as shown in Figure 3.2 and Figure 3.3, the trainees were introduced to PROPATHW software to determine the working fluid, ammonia's thermodynamic properties.

Site visit and training on Kumejima OTEC demonstration plant was very good because it provided us with a real OTEC system using an actual deep seawater to run the power plant and the turbine. Calculation of vapor power cycle using R134a working fluid at Kumejima OTEC double rankine cycle power plant provided a real reverse engineering design analysis. Calculation of evaporator power, condenser power, turbine power and pump power gives a good case study for Malaysian OTEC power plant system.


Shuhaimi Mansor: 06/12/19 – OTEC Training Turbine Power (Ideal case)

$mv := 4.6$
$h3 := 410.95$ T=29.06, P=0.8019 MPa, find s and h from REFPROP9
$h4 := 406.19$ isentropic s1=s2
$WTi := mv \cdot (h3 - h4)$ $WTi = 21.896$ kW
Evaporator mass flow rate, $me := \frac{mv}{0.7}$
$h6 := 221.83$
$h7 := 356.88$
$Qe := me \cdot (h7 - h6)$ $Qe = 887.471$
$h1 := 217.82$
$Qc := mv \cdot (h4 - h1)$ $Qc = 866.502$

Qe=Cp mws (Tin-Tout), knowing Qe,Tin and Tout, can calculate mws

$Cp := 4.2$
$Tin := 26.8$ $Tout := 23.8$
$mws := \frac{Qe}{Cp \cdot (Tin - Tout)}$ $mws = 70.434$

Checking using back calculation $Qe := Cp \cdot mws \cdot (Tin - Tout)$ $Qe = 887.471$
$Tin := 10.9$ $Tout := 8.3$
$mcs := \frac{Qc}{Cp \cdot (Tin - Tout)}$ $mcs = 79.35$

Pump Power
Method 1
$m4 := mv$
$h1 := 217.82$ T=12.21, P=0.6669 MPa, find s and h from REFPROP9
$h2 := 218.03$
$Wp := m4 \cdot (h2 - h1)$ $Wp = 0.966$ kW
Knowing Qe+Wp=Qc+Wt, then Wt=Qe-Qc+Wp, back calculation to check/compare turbine power Wt
$Wt := Qe - Qc + Wp$ $Wt = 21.933$ kW

Figure 3.3: Calculation of turbine power to introduce REFPROP software to determine R134a thermodynamic properties

3-2 Heat transfer (Heat exchanger)

Basic theory of heat exchanger was shared and explained during this training. Heat transfer coefficient was determined from semi-empirical method of heat transfer chart. Site visit to IOES Imari OTEC test rig was very useful to understand how the power plant was being designed and built for educational, research and development purposes. Explicit training on the heat exchanger design and built and the know-how to integrate it to other systems as a complete facility to simulate and demonstrate the OTEC system was very comprehensive. On the other hand, site visit to Xenesys Inc. Imari Plant was very effective and participants acquired good insights and understanding about the configuration design, fabrication, installation and testing of several types and sizing of heat exchanger design. The enormous heat exchanger manufacturing plant was simply magnificent.

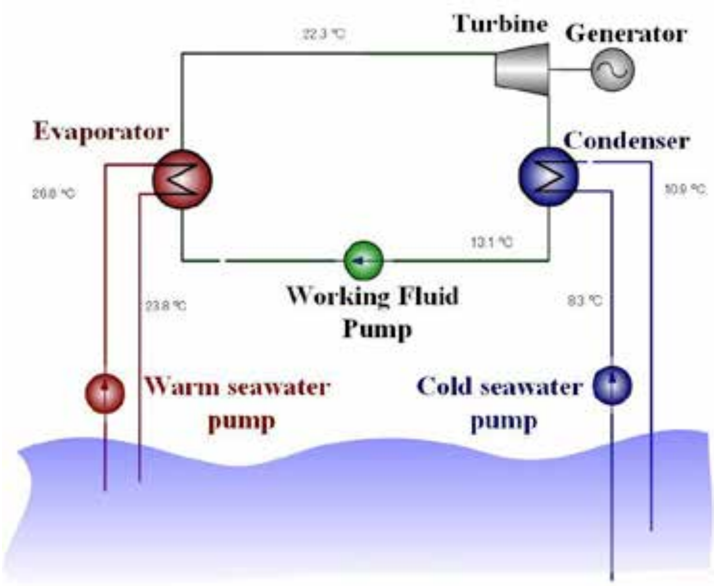


Figure 3.2: An example of design temperatures – OTEC plant

4. BASIC ENGINEERING SKILL TRAINING FOR OTEC AT IOES

4-1 OTEC experimental facilities

The Institute of Ocean Energy, Saga University (IOES) is an international centre for the study of ocean energy, specifically in Ocean Thermal Energy Conversion (OTEC) in Japan and in the world. IOES has a history of more than 50 years with vast research activities. IOES has developed its own new invention, Rankine cycle, Uehara cycle, the OTEC Cycle and a test rig (plant) was installed in IOES Imari, Japan.

OTEC power plant operates on a vapor cycle where working fluid becomes vapor after exchanging the heat with warm seawater/water, expanding it in a prime mover, exhausting it to a condenser, where it is changed to liquid state at low pressure and then returning the liquid working fluid by a pump to the evaporator as shown in Figure 4.1.

Visit to the OTEC IOES laboratory provided an opportunity to all participants to understand the whole process of OTEC including, set-up methods, parameters to consider during design and the commonly used software. The short exposure and hands-on experience to the software allowed participants to get a feel on how the system reacts to different flow rate and temperature. Besides, the desalination facilities are also observed and this helps participants to understand the whole process which will be implemented in H-OTEC system in Malaysia.

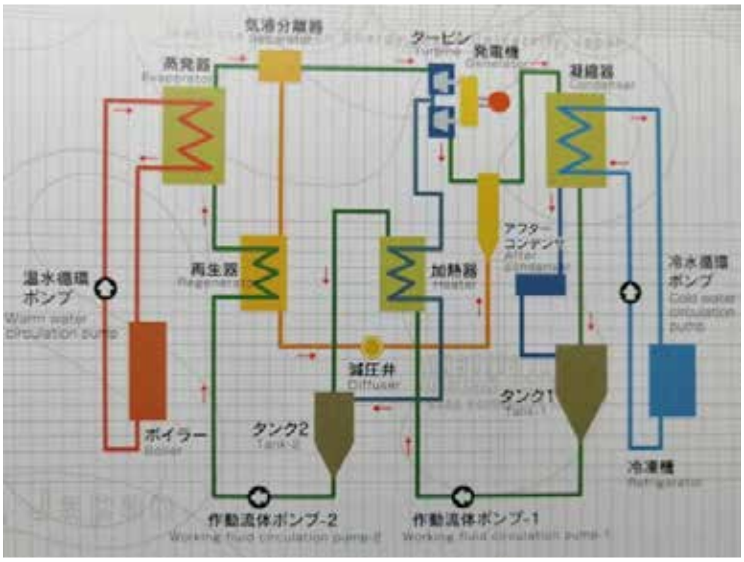


Figure 4.1: 30 kW ammonia/water cycle for OTEC in IOES

4-2 15 kW OTEC operation

In Prof. Dr. Yasuyuki Ikegami's class, the fundamental theory of OTEC technology and its difference with the conventional power plant was explained. OTEC applies Linear Thermal Expansion Coefficient (LTEC) which gives low Carnot efficiency then a steam turbine. The fundamentals on how to design the OTEC system based on Saturated Rankine cycle were explained in depth and comprehensive. Participants are then given examples and actual output from the OTEC experimental facilities are used to calculate the efficiency of net power.

4-3 Experimental data analysis

The lecture series delivered by Dr. Takeshi Yasunaga, Prof. Dr. Yasuyuki Ikegami and Emeritus Prof. Dr. Tsutomu Nakaoka gave participants an excellent understanding of technical and conceptual knowledge of OTEC design and evaluation. Then, participants were given a chance to visit the IOES's OTEC Laboratory Control Room. This slot gave us an excellent opportunity to apply our theoretical, conceptual understanding and experience at firsthand on how the theory and principles of OTEC system are being applied in reality.

4-4 Heat exchanger for OTEC (Visit to Xenesys Inc. OTEC R&D centre)

Xenesys Inc., OTEC R&D centre visit gave the participants a firsthand experience on the development process of OTEC equipment (specifically on the OTEC's heat exchanger), including the OTEC system set-up, layout and machine orientation and specification, design consideration and the selection of material. Furthermore, this visit also strengthened the networking between industry-academia collaboration between collaborators and technology providers.

Plate heat exchanger is a type of heat exchanger that uses metal plates to transfer heat between two fluids (in this case, seawater -> working fluid). This type of heat exchanger has a major advantage over the conventional type of heat exchanger. In plate type the fluids are exposed to a much larger surface area because the fluids are spread out over the plates. This facilitates the transfer of heat, and greatly increases the speed of the temperature change as shown in Figure 4.2.

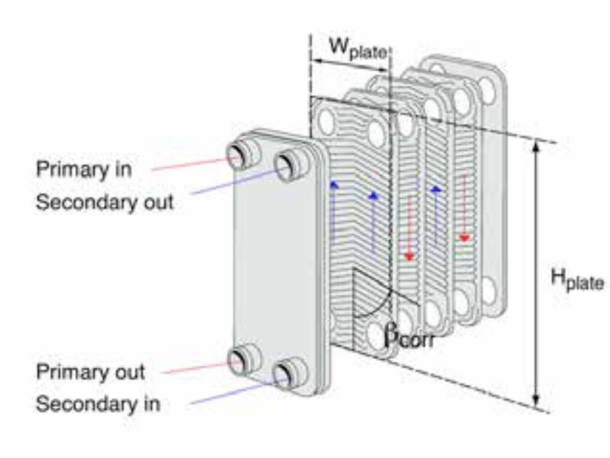


Figure 4.2: Plate-Type heat exchanger

Example of question during this training:

Calculate of the Overall Heat Transfer Coefficient U_E of Plate-Type Evaporator. Assume that the heat transfer coefficient in warm sea water side is 5000 W/(m2 K), the heat transfer coefficient in working fluid side h_{WF} is 10000 W/(m^2 K), the thermal conductivity λ is 16.5 W/(m K) and the thickness of plate δ is 1 mm.

λ = k = 16.5 W/(m K)
hWS = 5000 W/(m2 K)
hWF = 10000 W/(m2 K)
δ = 1 mm

$$U_E = \frac{Q_E}{A_E \Delta T_{me}} = \frac{1}{h_{WS}} + \frac{\square}{\square} + \frac{1}{h_{WF}} = \frac{1}{\frac{1}{h_{WS}} + \frac{\square}{\square} + \frac{1}{h_{WF}}} = \frac{1}{\frac{1}{5000} + \frac{0.001}{16.5} + \frac{1}{10000}} = 2773 \text{ W/m}^2\text{ K}$$

5. 100 KW PILOT PLANT IN KUMEJIMA

From 6th to 9th December 2019, the SATREPS OTEC training program was held in Kumejima, in the region of Okinawa. The participants were welcomed by Mr. Benjamin Martin and Mr. Shin Okamura, representatives from the Kumejima OTEC facility centre. They came to receive us from the Kumejima airport. This specific training was held to give an exposure to all participants on the working principles and maintenance procedure of the 100kW OTEC plant and also the seawater intake facility.

5-1 OTEC experimental facilities

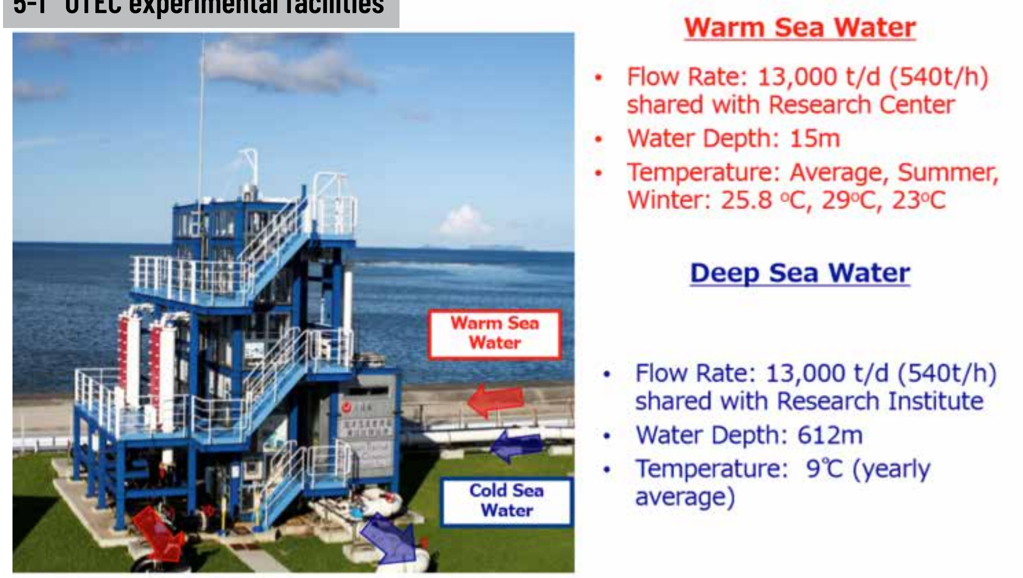


Figure 5.1: 100 kW OTEC Demonstration Plant at Kumejima & its flow capacity

Introduction to these facilities began with a slide presentation by Mr. Benjamin, titled 'INTRODUCTION TO DESIGN, GENERAL OPERATION AND CONTROL OF THE OTEC DEMONSTRATION FACILITY' before a site visit to the plant itself (due to storm and rain). The OTEC Experimental Facilities consist of;

1. Computer Control Room, inside the ODRC Building
2. 100kw OTEC Demonstration Plant
3. Desalination Demo Unit
4. Electrical & Manual Control Room

The 100kW OTEC demonstration plant consist of two units (double rankine cycle) which are Unit A and Unit B as shown in Figure 5.1. Unit A was built in 2012, whereas Unit B in 2016 (as shown in Figure 5.2). Each unit produces 50 kW, with their own set of evaporator, condenser and turbine. The working fluid used in this OTEC plant is R134a, Hydro-Fluoro-Carbons (HFCs). Although, the design of the heat exchanger can use ammonia (NH3) as working fluid, R134a was chosen to fulfill the local authority's law which forbids the usage of NH3.

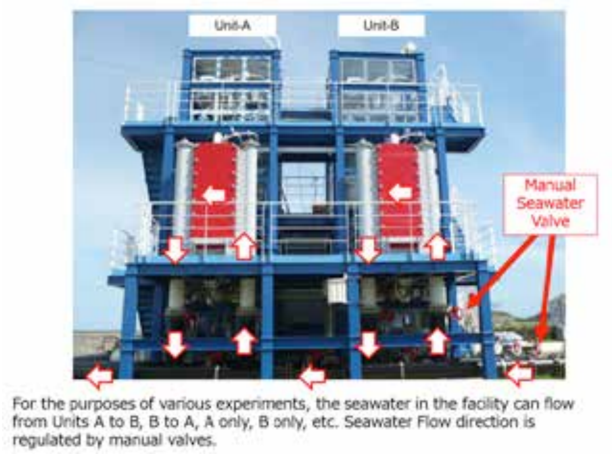


Figure 5.2: Unit A and Unit B system

5-2 100kW OTEC maintenance & operation

Figure 5.4: Overall layout of OTEC control system

Control and operation of OTEC demonstration plant can be done manually or by computer, although most of the time this plant is operated and monitored via computer in the facility as shown in Figure 5.4. But in some cases, the plant is operated manually such as during the final stage of the opening and closing of the plant. Participants have been taught how to operate the demonstration plant by computer control system, step-by-step, from system start-up to controlled stop as shown in Figure 5.5.

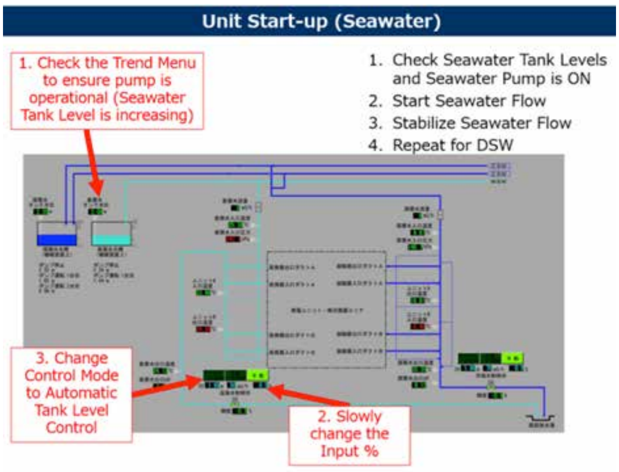


Figure 5.5 Example of step-by-step procedure for seawater unit start-up (Control System)

The maintenance of OTEC plant is made regularly as it is due to the corrosion because of the breeze from the sea.

Figure 5.3: Desalination & Hydrogen production demo unit container, located next to OTEC demonstration plant which is the IOES satellite in Kumejima

5-3 Seawater Intake facility

The seawater intake for this OTEC demonstration plant is located near to the shore and nearer to the OTEC plant itself. It is for the reason that the length of the pipe used to carry the seawater is reduced and optimized. The warm seawater is taken from the sea by natural flow and sea wave. The deep-sea water on the other hand is taken from 612m depth, under the sea. The surface sea water temperature is about 28oC during summer and 22oC during winter and the deep-sea water is around 8oC throughout the year. The deep-sea water that has been collected is pumped into a tank and then distributed to other related industries and to OTEC demonstration plant (when necessary).

WSW Intake specifications are as follows:

Location area is as shown in Figure 5.6 and 5.7:
Distance of 615m from surface seawater intake point and depth length (DL) is 13m from surface
Surface seawater intake pipe diameter: 560mm
Flow rate: ~ 540 m3/h
Depth: 13m
WSW Inlet Temp: 23oC

Fig.5.6: Picture of WSW intake segment (Assembled in the construction)

Fig.5.7: Picture of WSW intake segment (Installation)

DSW Intake specifications are as follows:

The optimum distance from the shore is about 2300m (as shown is Figure 5.8) from deep seawater intake point and DL is about 615m from surface x 2 pipes

Deep seawater intake pipes diameter: 280mm, 380mm, 450mm and 300mm

Flow rate: ~ 540 m3/h

Depth: about 615 m

DSW Inlet Temp: 9oC

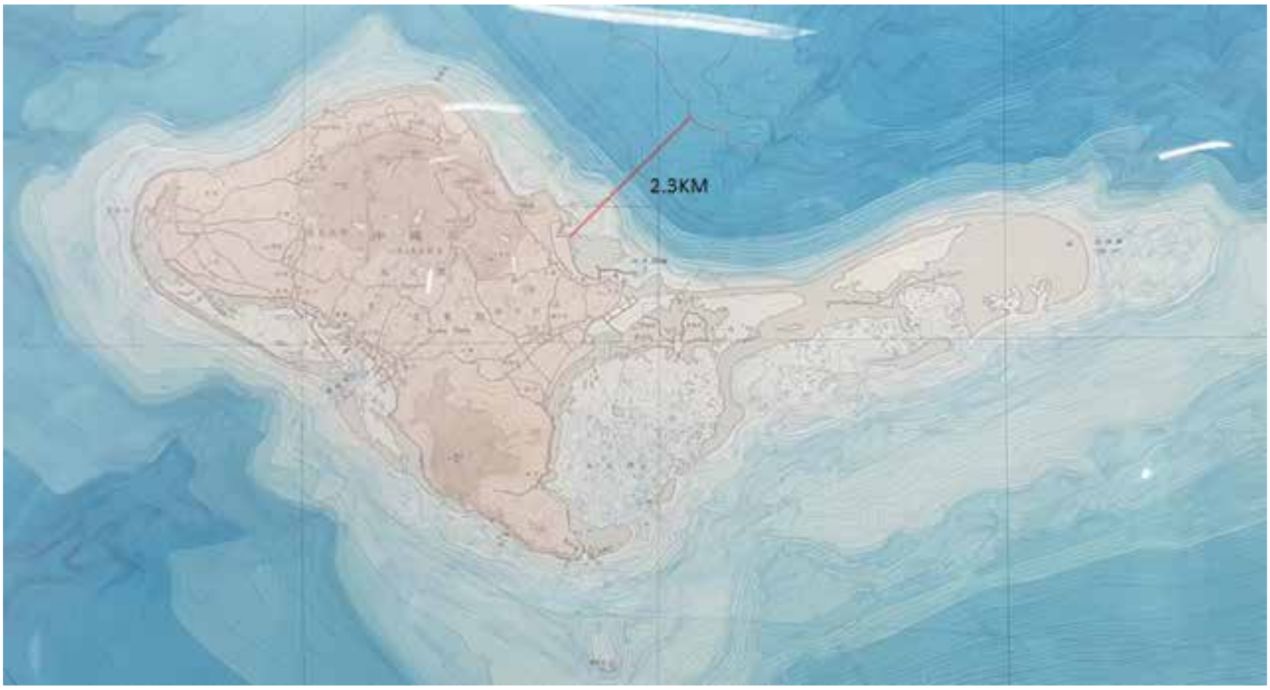


Figure 5.8: Distance of DSW pipe

6. DEEP SEAWATER APPLICATION AND KUMEJIMA MODEL

6-1 Deep seawater application in Kumejima

Deep seawater application in Kumejima has long been there and utilized in the industrial sectors even before OTEC technology was introduced. Four main elements of deep seawater application in Kumejima industries are the economical profit, food production, education and environment conservation. Agriculture and aquaculture industries utilized most of the deep seawater supply, but have contributed to their highest revenues. The main aquaculture activities using cold deep seawater are the oyster farms, prawn's hatchery and seaweed culture. These industries are improving their research and development towards quality and massive production of healthy, safe and nutritious food supplies as some of the water is also processed for drinking water with tremendous health benefits. Utilisation of nutrient rich deep seawater in skincare and cosmetic range is also one of Kumejima's main products that give high profit return as only minimal volume of deep seawater is required. Apart from economy and food production, the deep seawater is also supplied to the coral nursery for the recovery of bleached corals due to global warming. In the summertime, the deep seawater runs through the built-in pipeline for cooling in the OTEC facility building as a substitute for air-conditioners. The OTEC demonstration plant in Kumejima serves not only as an educational and research platform, but also an attraction to the public and the world.

6-2 Kumejima model

The Kumejima model was introduced as a result of potential energy generation from seawater temperature difference, not limited to the deep seawater related industries. The plant has been operating since 2013 producing a total of 100kwatt. Although it was mainly used for demonstration purposes, it has helped a lot in understanding the build-up concept of the plant as well as the maintenance involved which serves as a reference for Malaysian model and other OTEC commercial plant model.

6-3 Education / Understanding of deep seawater potential in Kumejima

The development of OTEC technology in Kumejima involves awareness amongst the locals through education and government support especially the local authorities. School tours to the OTEC demonstration plant is one of the occasional activity that is conducted. It is professionally guided by the OTEC experts as their social responsibilities towards communities and societies in their vicinity. The deep seawater potential in Kumejima will develop further and will continue to establish as the local authorities are very supportive and always promoting deep seawater products of Kumejima and the world.

7. IMPRESSION FROM PARTICIPANTS

7-1 Impression

The training was very informative, educational and useful for all participants to visualize OTEC technology and its spin-off industries in Malaysian context. All participants from different backgrounds and experiences were brought together and taught about the basics of thermodynamics, application of OTEC system, OTEC operation, maintenance and utilizations. All of the experts, guides, facility instructors from the Japanese side were very good and have given their best in conducting this SATREPS OTEC training. All of the participants are very thankful and appreciative towards organizing teams' hospitality throughout the program in IOES, Imari and Kumejima.

7-2 Recommendations / suggestions for next training program

Overall, the content and activities were very good, comprehensive and beyond expectation. However, some suggestions for improvement would be to increase the training and learning time for basic thermodynamics, heat exchangers and the business model. It would provide a better understanding and thinking time for all participants. Another recommendation would be to conduct this training in the month of April or May to avoid rainy season, storm and other climate hurdles.

8. SUMMARY

The first SATREPS OTEC training was very useful and comprehensive for all the participants in order to understand the fundamentals of OTEC and its application. The training content was appropriate and well aligned with the project outcome. Participants were able to visualize the future of Malaysian OTEC Model. There were several visits to OTEC spin-off industries, such as shrimp farm, deep-sea-water bottling factory, seaweed farm, cosmetic outlet and factory and all were very impressive and excellent. Participants enjoyed the hospitality and warm welcome from IOES staffs in Imari and Kumejima Mayor and county office staffs. Nevertheless, the accommodation and meals were also well arranged by the organisers, especially to suit participants' needs and requirements. Round trip flight was also comfortable for participants to travel from Malaysia to Japan via Bangkok. Flights to Kumejima was also nice and comfortable. Overall transportation during the training was manageable even though it was 10 members moving together. Some ideas for improvement especially on the scheduling, OTEC content and delivery would be; provide OTEC basics training (3 – 5 days) in Malaysia before the hands-on training in Japan. The idea is to expose the participants with OTEC technical basics in advance which will ease and provide them the know-how and for better understanding. Participants will be able to think critically and creatively while the hands-on training in Japan. These approaches will ensure that the project output number 5 on knowledge and technology transfer will be effectively achieved. OTEC research and development, its stake holders will grow vigorously.

Training participants in IOES, Imari

Participants of the training with Prof. Dr. Kamimoto (6th from left) and Ms. Sawatari (3rd from right), JST observers who joined the training on 6 and 7 December 2019

ANNEX

ANNEX II MALAYSIA PARTICIPANTS LIST

NO.	NAME	INSTITUTE	SUB PROJECT / SPECIALTY
1.	Ts. Dr. Sathiabama T. Thirugnana	UTM	PJ No. 2 / Electrical Engineering
2.	Dr. Suriyanti Su N.P.	UKM	PJ No. 4 / Marine Science
3.	P.M. Ir. Dr. Farah Nora Aznieta Binti Abd Aziz	UPM	PJ NO. 1 / Civil Engineering
4.	Assoc. Prof. Dr. Mohd Khairi Abu Husain	UTM	PJ No. 1 / Civil Engineering
5.	Assoc. Prof. Dr. Shamsul Sarip	UTM	PJ No. 1 / Mechanical Engineering
6.	Prof. Ir. Dr. Shuhaimi Mansor	UTM	PJ No. 5 / Aeronautical Engineering
7.	Dr. Muhammad Fadhil Syukri Ismail	UPM	PJ No. 7 / Aquaculture
8.	Dr. Yeong Hui Yin	UM	PJ No. 6 / Algae Biotechnology
9.	Mr. Ridhwan Ruslan	UTM	PJ No. 9 / Mechanical Engineering
10.	Mr. Azrin Ariffin	UTM	PJ No. 1 / Mechanical Engineering

https://www.utm.my/satreps/projects/list-of-project

ANNEX III JAPANESE TRAINER LIST

NO.	NAME	ORGANIZATION	TRAINING COURSE
1.	Prof. Dr. IKEGAMI Yasyuki	IOES	OTEC, Thermodynamics
2.	Special Appointed Prof. Dr. NAKAOKA Tsutomu	IOES	Heat transfer and heat exchanger for OTEC
3.	Assistant Prof. Dr. YASUNAGA Takeshi	IOES	Introduction to IOES facilities. Seawater desalination & H-OTEC, Experimental OTEC data analysis
4.	Dr. SAKURAZAWA Shunji	Xenesys	Introduction of Xenesys product line
5.	Mr. Benjamin Martin	GOSEA	Introduction to Kumejima OTEC pilot plant and DSW applications
6.	Mr. OKAMURA Shin	Xenesys	100kW OTEC data analysis, operation and maintenance
7.	Mr. OKUNO Tomoya	SU (M1)	15 kW OTEC - hands-on experiment activity
8.	Mr. NAKAMURA Taisei	SU (B4)	15 kW OTEC - hands-on experiment activity

ANNEX IV PRESENTATION ON TRAINING GUIDANCE AND EXPERIMENT OF OTEC (IOES) FACILITY AND DATA ANALYSIS (PART 1, PART 2, PART 3)

The 1st on the site training on OTEC and DSW applications held on 2 - 10 Dec. 2019

Annex IV (Part 1) -Training guidance and IOES facility tour-

CONFIDENTIAL RELATED PARTIES ONLY

1

Documentation & Precautions

1. Documentation

The documents are requirement for the payment of transportation tickets, accommodation, meals and daily allowance under Saga University's rule.

2. Insurance

JICA prepare the insurance during the trip for the training.
*Please sign to your insurance card.

3. Foods & drinks

IOES prepares the suitable snacks, drinks and foods. Please enjoy them by your own risk. We are very welcome any questions about the substances and ingredients.

4. Publication permit

This training includes unpublished information and data. Please do not publish any unpublished information and data without permission from the Japanese counterpart.

2

Training Guidance & IOES tour

2. Training Purpose

The training program "On the site training on OTEC and DSW applications" is aimed for construction of the Malaysia Model for low carbon and sustainable society in Malaysia and the world. In the program, the participant leran:

- the OTEC basic knowledge, OTEC facility maintenance & operation as well as analysis of the data using OTEC testing plants in IOES Imari satellite and Okinawa prefectural pilot plant in Kumejima deep seawater research center, and

- the present condition of DSW application in Kumajima, Japan

3. Entire training schedule

4. IOES tour

3

Training Schedule

2 Dec. Training Guidance, IOES tour & Welcome reception

3 - 4 Dec. OTEC training in IOES Imari satellite

5 Dec. Move to Kumejima

6- 9 Dec. OTEC and DSW training in Kumejima

(8 Dec. Day-off)

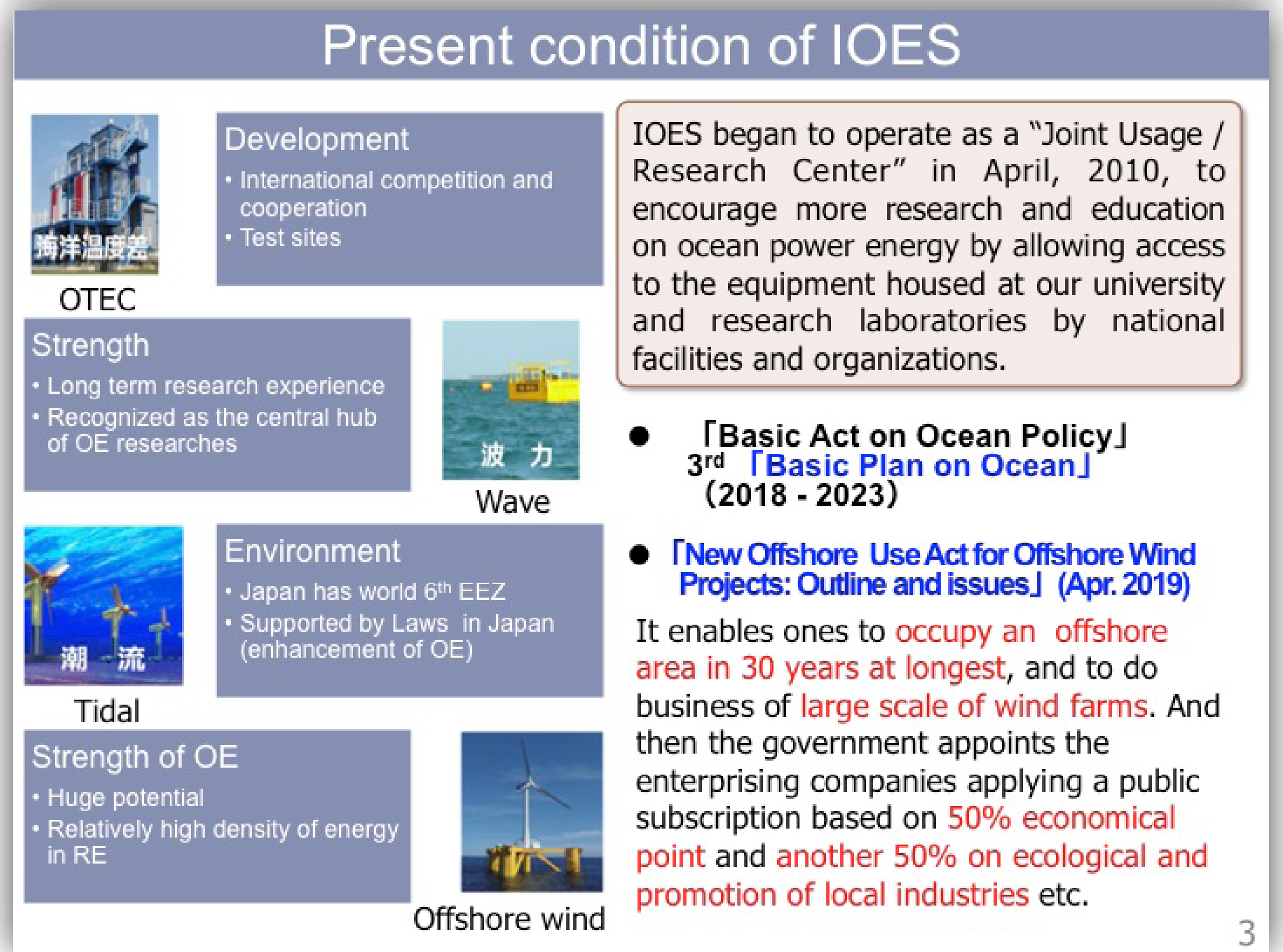
10 Dec. Move to Fukuoka, Wrap-up meeting

11 Dec. Departure

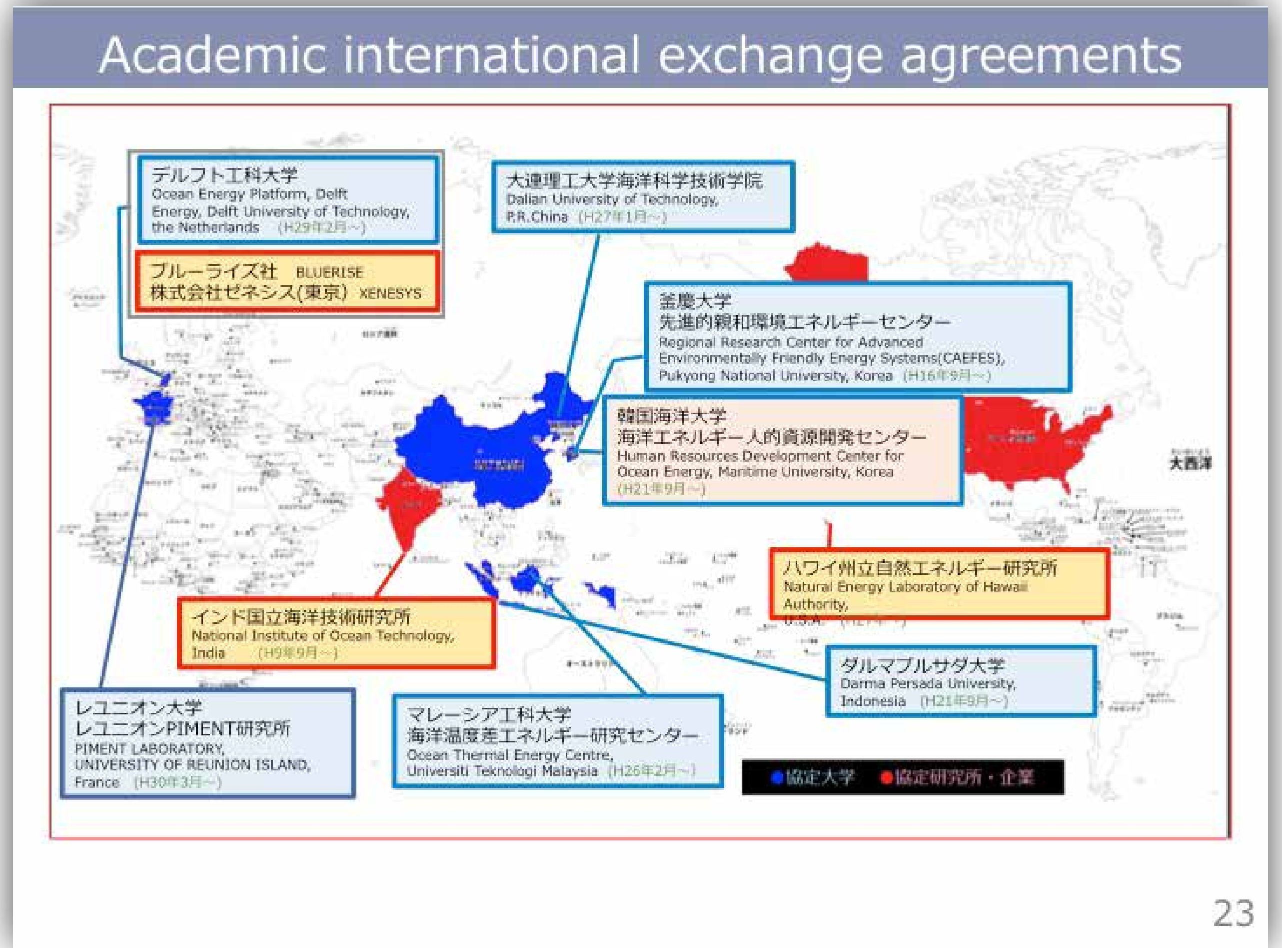
* For more detail, please refer to the handout schedule

4


国立大学法人佐賀大学
海洋エネルギー研究センター
Institute of Ocean Energy, Saga University, Japan
伊万里サテライト施設見学
Imari satellite facility tour
IOES
5

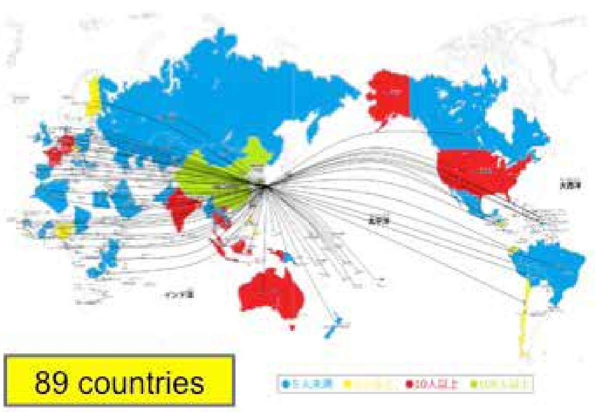

Present condition of IOES
Development
• International competition and cooperation
• Test sites
海洋温度差
OTEC
Strength
• Long term research experience
• Recognized as the central hub of OE researches
波 力
Wave
潮 流
Tidal
Environment
• Japan has world 6th EEZ
• Supported by Laws in Japan (enhancement of OE)
Strength of OE
• Huge potential
• Relatively high density of energy in RE
Offshore wind
IOES began to operate as a "Joint Usage / Research Center" in April, 2010, to encourage more research and education on ocean power energy by allowing access to the equipment housed at our university and research laboratories by national facilities and organizations.
「Basic Act on Ocean Policy」
3rd 「Basic Plan on Ocean」
(2018 - 2023)
「New Offshore Use Act for Offshore Wind Projects: Outline and issues」 (Apr. 2019)
It enables ones to occupy an offshore area in 30 years at longest, and to do business of large scale of wind farms. And then the government appoints the enterprising companies applying a public subscription based on 50% economical point and another 50% on ecological and promotion of local industries etc.
3

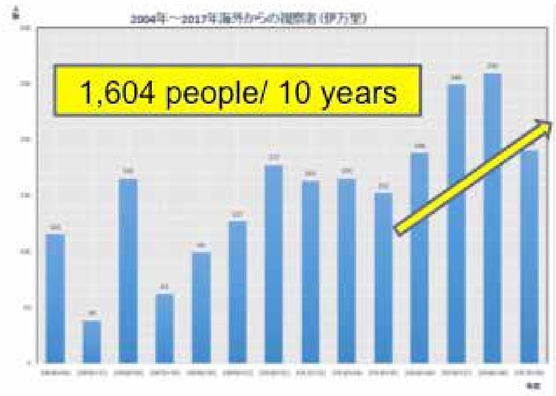

Location and Facility
Location
Headquarter（Hojo, Saga city）
Office, Meeting room
Imari satellite（Imari city）
Experimental apparatus, Super-computers, Accommodation
Kumejima satellite（Kumejima town, Okinawa） Experimental apparatus
Imari Satellite
Est. 2003
Kumejima Satellite
Est. 2014
Facility
OTEC related（6 devices）
Ocean Fluid related（4 devices）
Material recovery（1 devices）
Hydrogen related（3 devices）
Chemical analysis（8 devices） Total 22 deveices
Technical report, Database… etc
OTEC
Desalination
Hydrogen productio
and storage
2D Wave tank
Circulation tank
DOW simulation tank
Lithium recovery
7


Academic international exchange agreements
デルフト工科大学
Ocean Energy Platform, Delft Energy, Delft University of Technology, the Netherlands （H29年2月～）
ブルーライズ社 BLUERISE
株式会社ゼネシス(東京) XENESYS
大連理工大学海洋科学技術学院
Dalian University of Technology, P.R.China （H27年1月～）
釜慶大学
先進的親和環境エネルギーセンター
Regional Research Center for Advanced Environmentally Friendly Energy Systems(CAEFES), Pukyong National University, Korea （H16年9月～）
韓国海洋大学
海洋エネルギー人的資源開発センター
Human Resources Development Center for Ocean Energy, Maritime University, Korea
（H21年9月～）
ハワイ州立自然エネルギー研究所
Natural Energy Laboratory of Hawaii Authority,
インド国立海洋技術研究所
National Institute of Ocean Technology, India （H9年9月～）
ダルマプルサダ大学
Darma Persada University, Indonesia （H21年9月～）
レユニオン大学
レユニオンPIMENT研究所
PIMENT LABORATORY, UNIVERSITY OF REUNION ISLAND, France （H30年3月～）
マレーシア工科大学
海洋温度差エネルギー研究センター
Ocean Thermal Energy Centre, Universiti Teknologi Malaysia （H26年2月～）
●協定大学 ●協定研究所・企業
23

International contribution

Oversea visitor is increasing
For 10 years（2008～2017） 1,604 people from 89 countries





International education programs

(1)「**Program of International Platform on Ocean Energy for Young Researcher**」supported by JST
(98 participants / 4 years from 8 to 17 countries)

(2) Internship program under joint research / usage program (Over 3 moth)
Malaysia（2 person：for 6 month, 2015） France（1 person：for 6 month, 2017）
Italia（1 person：for 5 month, 2018）

18

International internship students

Malaysia（2 person：for 6 month, 2015）
Kevin Fontaine
Ra Union（France）
(Mar. 2017 – Aug. 2017)

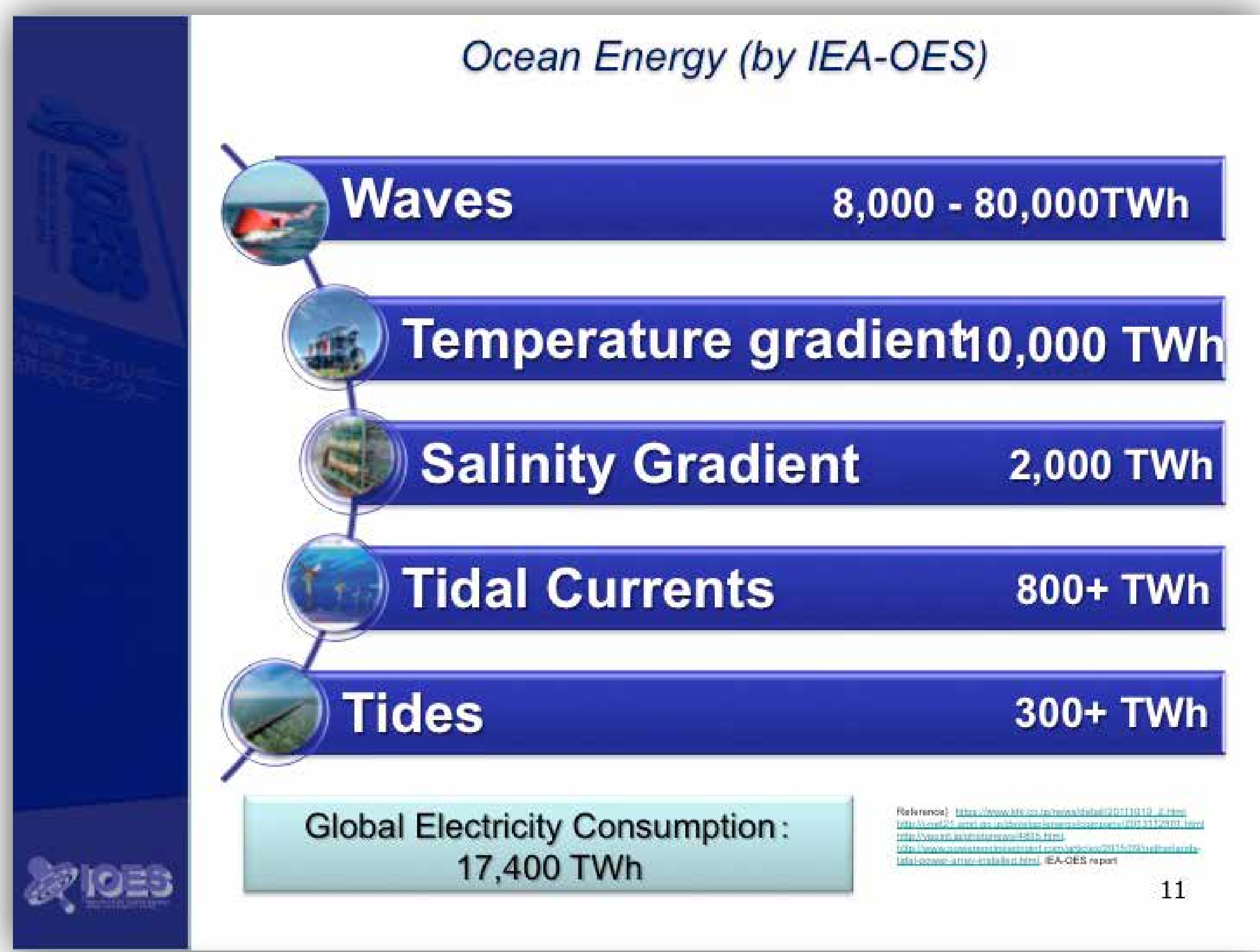
Martina Pinto
Roma（Italy）
(Sep. 2018 – Jan. 2019)

1st year of PhD student in IOES !!

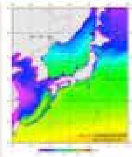
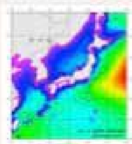
Lucas Ohata
Monperier（France）
(Sep. 2019 – Dec. 2019)

The Program of Support on International Internship and Joint Research Program for Young Researchers

This program supports overseas young researchers (35 years old or less) who will get a master's degree or a PhD by using any facilities in Institute of Ocean Energy, Saga University (IOES) to promote the international joint researches.



Characteristics of OE resource

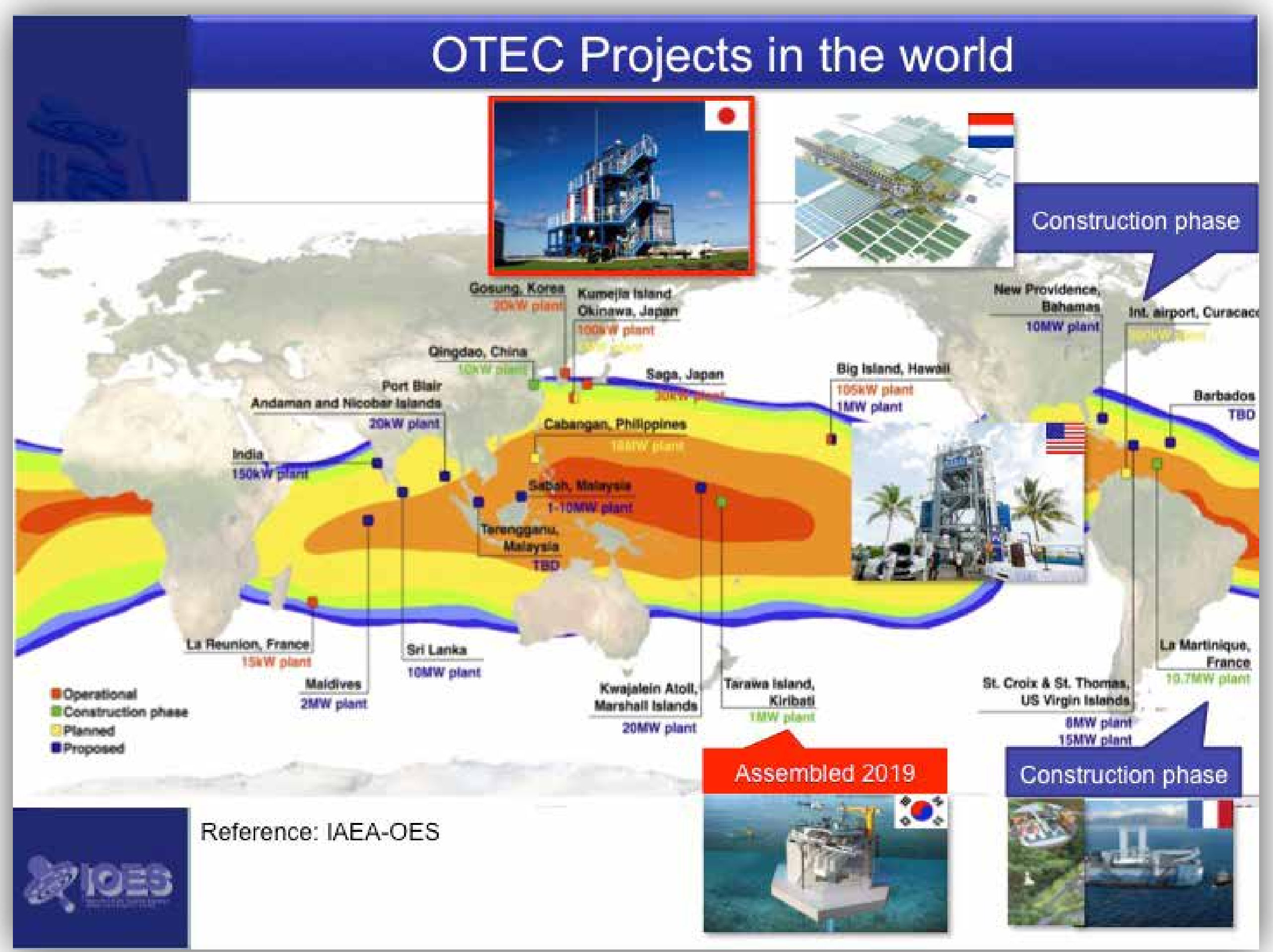
Resource	Strength	Weakness	Potential (Japan)
OTEC 	Stable power generation (7/24) High availability Predictable	Limited to subtropical ~ tropical zones (Suited to: Okinawa, Malaysia, Hawaii, Pacific islands…, etc)	
Wave 	Applicable to wider shore area	Limited to strong wave zones (Suited to: Yamagata, Iwate, Australia, Europe, North pacific ocean… etc)	
Tidal 	Relatively stable Predictable	Limited to strong tide area (Suited to: Coast of Goto islands, Kurushima strait, Scott land, North America and Indonesia… etc)	
Offshore wind 	Stronger and constant wind rather than land	Constant wind zones are preferable (Suited to: Coast of Fukushima, Akita, Goto islands, North Sea and China Sea… etc)	

Each OE resource has strength and weakness, then BEST MIX considering specific sites, efficient utilization should be considered
⇒IOES contribute to innovative, cross sectional researches

「Ocean Energy Demonstration Test Field in Japan」
– Selected by Cabinet Office-

1. Offshore Wind
   Niigata, Nagasaki, Saga
2. Wave power
   Niigata,
3. Tidal Current
   Niigata, Nagasaki, Saga
4. Ocean Current
   Niigata,
5. OTEC
   Okinawa

Recent development of Ocean Thermal Energy Conversion (OTEC)



OTEC Projects in the world
Construction phase
Gosung, Korea
20kW plant
Kumejia Island
Okinawa, Japan
100kW plant
Qingdao, China
10kW plant
Saga, Japan
30kW plant
Port Blair
Andaman and Nicobar Islands
20kW plant
India
150kW plant
Cabangan, Philippines
10MW plant
Sabah, Malaysia
1-10MW plant
Terengganu, Malaysia
TBD
Big Island, Hawaii
105kW plant
1MW plant
New Providence, Bahamas
10MW plant
Int. airport, Curacao
Barbados
TBD
La Reunion, France
15kW plant
Maldives
2MW plant
Sri Lanka
10MW plant
Kwajalein Atoll, Marshall Islands
20MW plant
Tarawa Island, Kiribati
1MW plant
St. Croix & St. Thomas, US Virgin Islands
8MW plant
15MW plant
La Martinique, France
10.7MW plant
Operational
Construction phase
Planned
Proposed
Assembled 2019
Construction phase
Reference: IAEA-OES
IOES

1MW OTEC by KRISO
KRISO
26 Sep. 2019
In Busan, Korea
Generated successfully on the coast of Korea
To be exported to Kiribati in 2020
IOES
KOREA RESEARCH INSTITUTE OF SHIPS AND OCEAN ENGINEERING
16

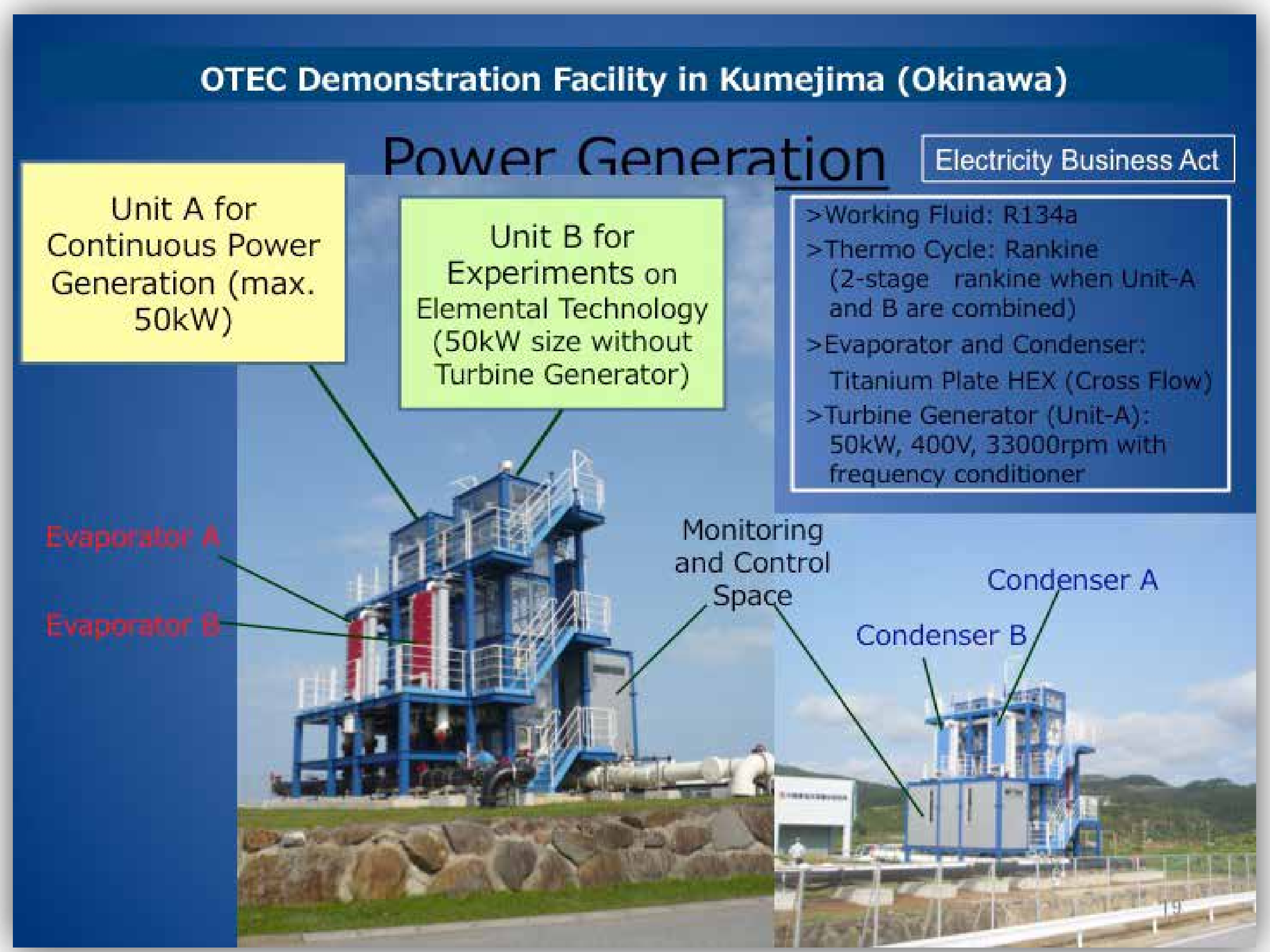
Go to NEW STAGE (Re START) of Real OTEC Technology to connect the electric grid for the first time in 15 years in the world.

From OPEC (in the 20th century)
To OTEC (in the 21st century)

17

Kume-island demonstration OTEC project

18


OTEC Demonstration Facility in Kumejima (Okinawa)
Power Generation
Electricity Business Act
Unit A for Continuous Power Generation (max. 50kW)
Unit B for Experiments on Elemental Technology (50kW size without Turbine Generator)
>Working Fluid: R134a
>Thermo Cycle: Rankine (2-stage rankine when Unit-A and B are combined)
>Evaporator and Condenser: Titanium Plate HEX (Cross Flow)
>Turbine Generator (Unit-A): 50kW, 400V, 33000rpm with frequency conditioner
Evaporator A
Evaporator B
Monitoring and Control Space
Condenser A
Condenser B


OTEC Demonstration Facility in Kumejima (Okinawa)
Deep and Surface Water
SURFACE WATER
• Flow Rate: Max. 13,000 t/d (540t/h) by the existing SW intake pipe and pump
• Temperature: annual ave. 25.8 °C, summer 29°C, winter 23°C
DEEP WATER
• Flow Rate: Max. 13,000 t/d (540t/h) by the existing SW intake pipe and pump
• Intake Depth: 612m by the existing SW intake pipe
• Temperature: annual ave. 9°C
SURFACE WATER
DEEP WATER
20


History
Mile Stones
Jan. 2013
Feb. 2013
Mar. 2013
Apr. 2013
May. 2013
Jun. 2013
28 Jan.
Construction
Started at Site
15 Apr.
Official
Operation
16 Jun.
Opening Ceremony
30 Mar. / 1st Power Generation Test Succeeded
Surface Water: 23.5 °C, 330t/h
Deep Water: 9.3 °C, 250t/h
Power Output: 3.1kW (for Test)
21


History
28 Jan. Kanegusuku Port, Kumejima
22

History

30 Jan. The Site, Kumejima

23

History

1 Feb. The Site, Kumejima

24

History

4 Feb. The Site, Kumejima

25

History

8 Feb. The Site, Kumejima

26

History

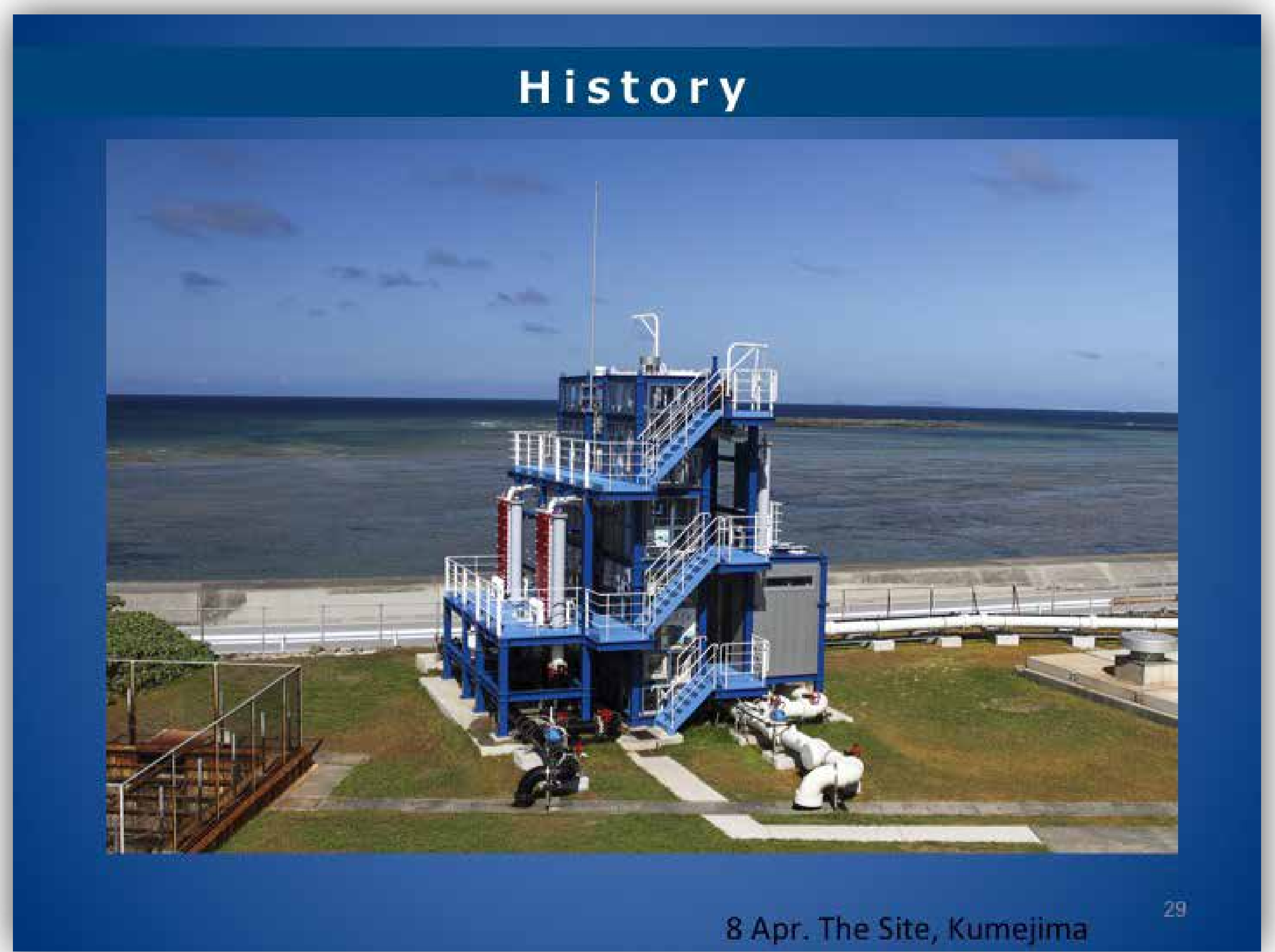
11 Feb. The Site, Kumejima

27

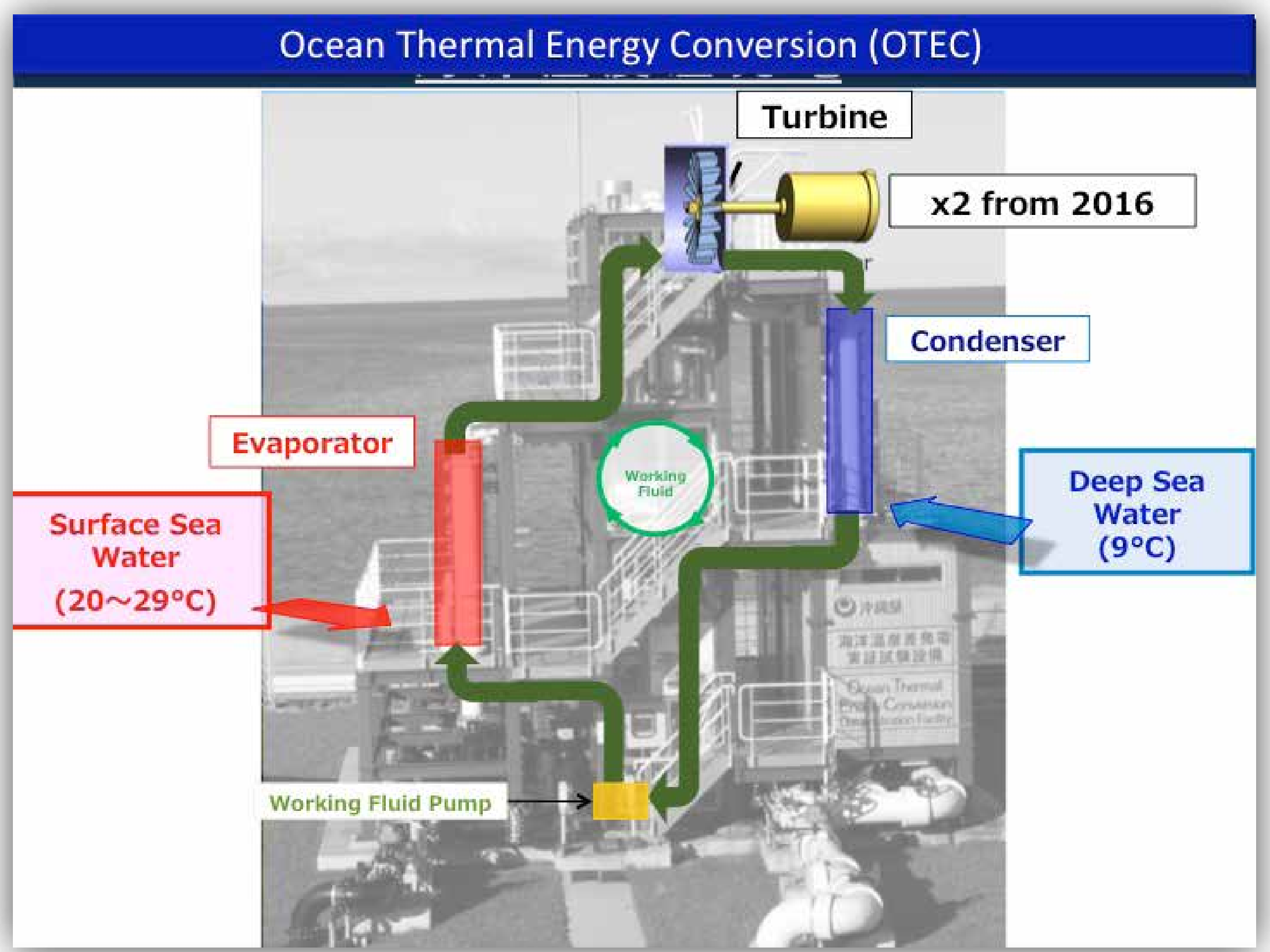
History

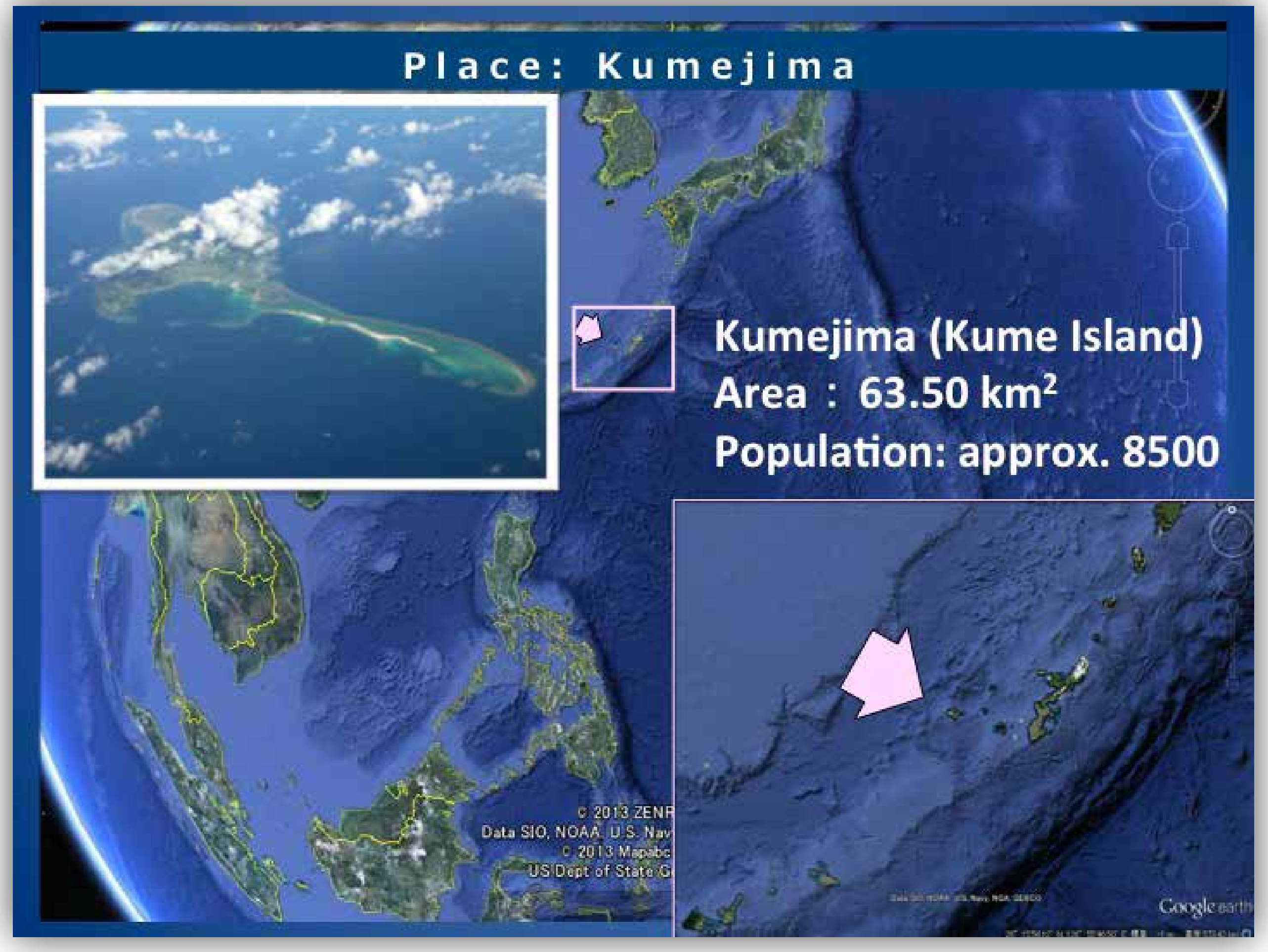
8 Mar. The Site, Kumejima

28


History
8 Apr. The Site, Kumejima
29

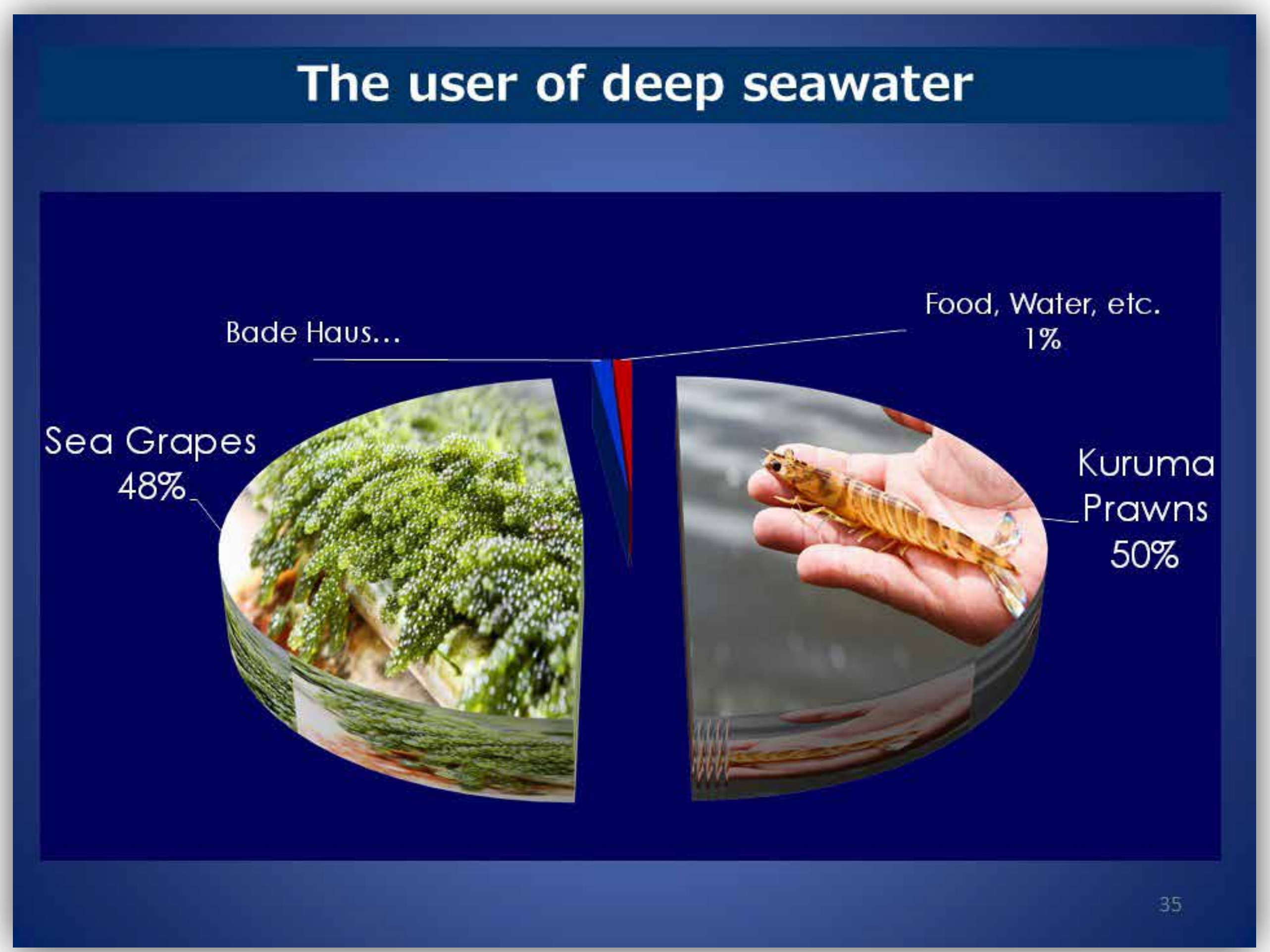

Demonstration project in Kumejima
IOES

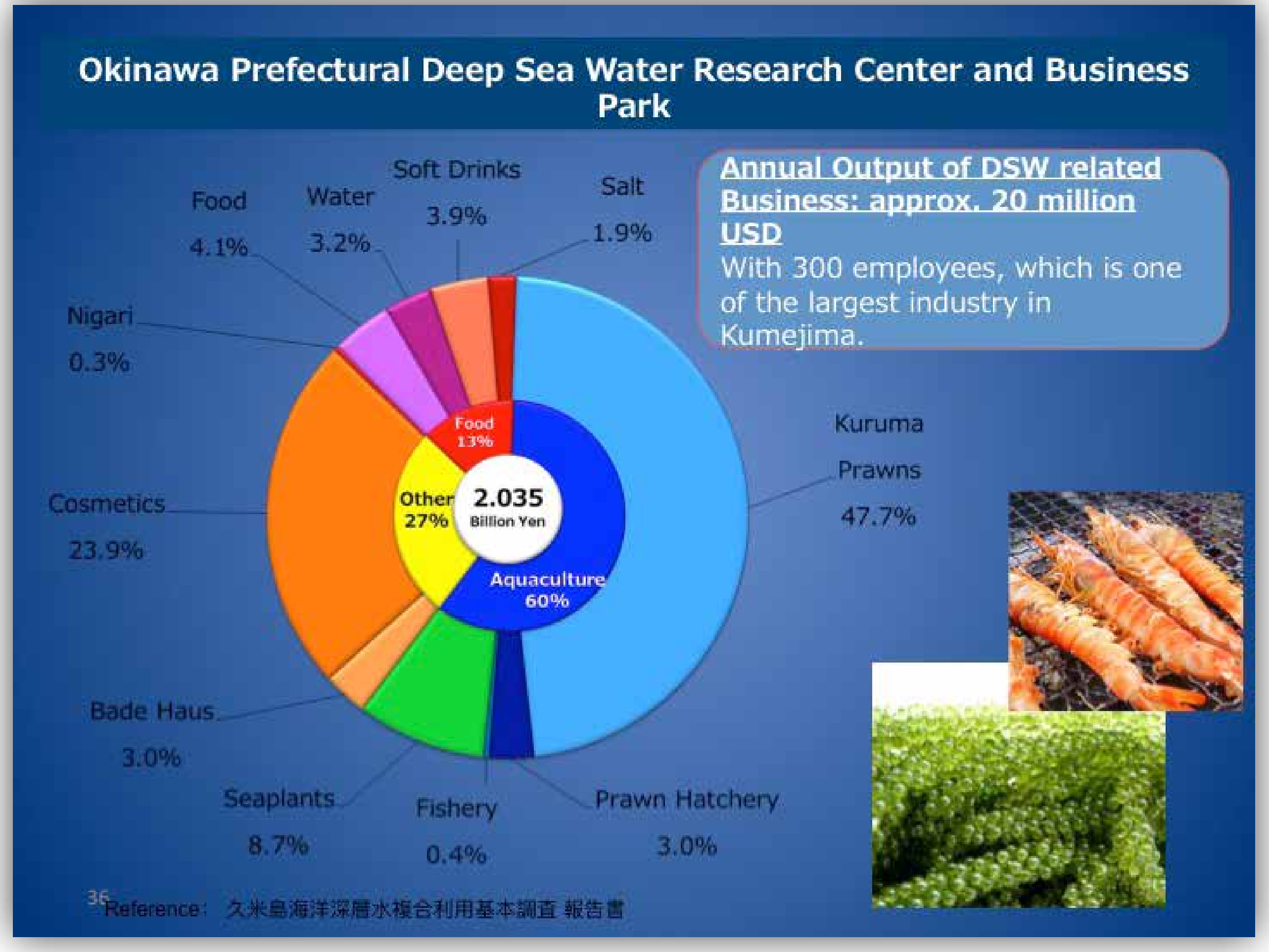

Ocean Thermal Energy Conversion (OTEC)
Turbine
x2 from 2016
Condenser
Evaporator
Working Fluid
Surface Sea Water
(20～29°C)
Deep Sea Water
(9°C)
Working Fluid Pump

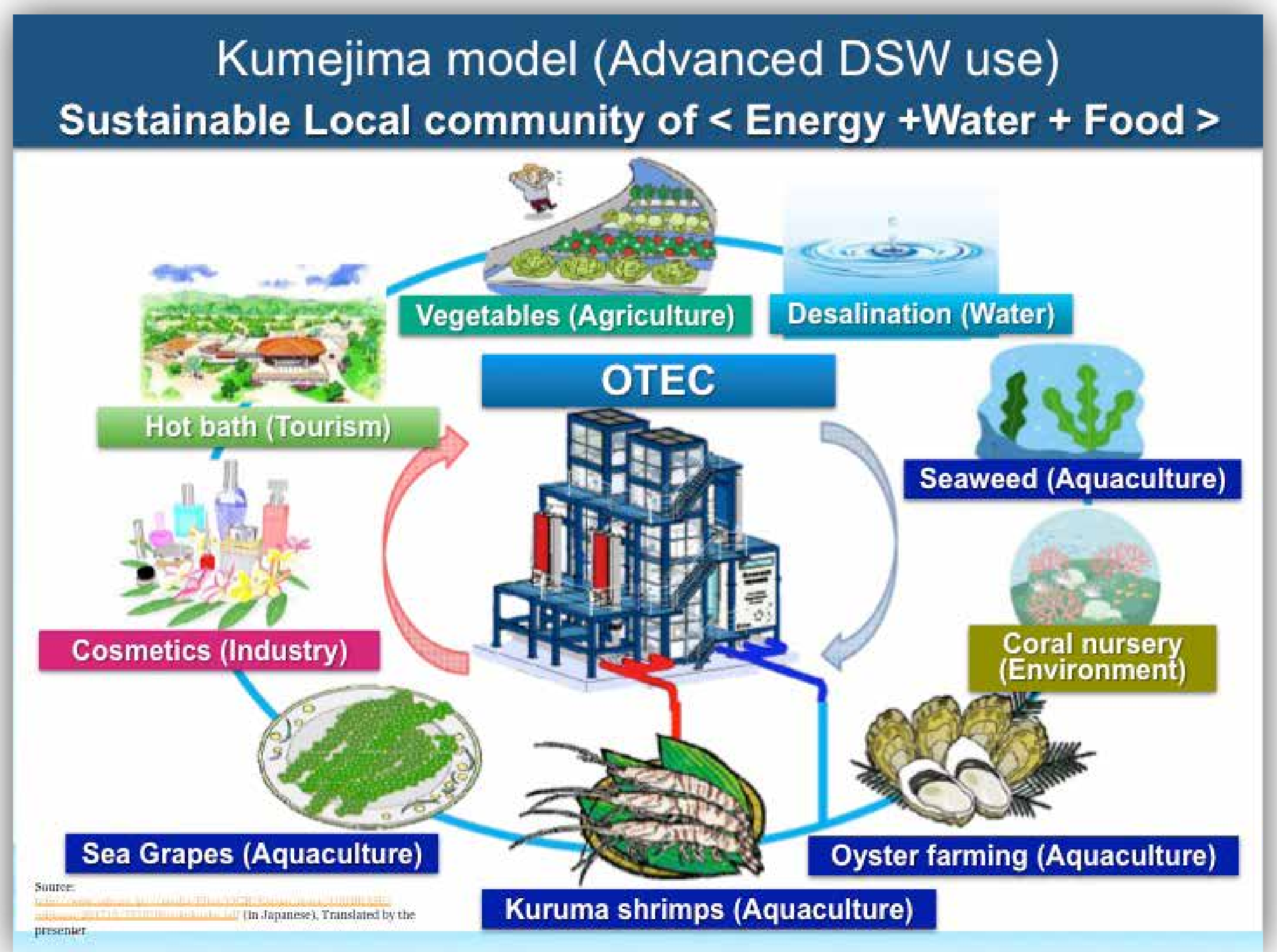

Place: Kumejima
Kumejima (Kume Island)
Area : 63.50 km²
Population: approx. 8500
© 2013 ZENR
Data SIO, NOAA, U.S. Nav
© 2013 Mapabc
US Dept of State G


OTEC Demonstration Facility
in Kumejima (Okinawa pref., Japan)
Okinawa Prefectural Deep Sea Water
Research Center, since 2000
OTEC Demonstration Facility
(Picture on 10 March. 2013)


Okinawa Prefectural Deep Sea Water Research Center and Business Park
Business Park Using DSW
- Young Prawn Culture
-Seaweed Culture
- Cosmetics Factory
Okinawa Prefectural DSW
Research Center
DSW Pump-up Capacity: 13,000 ton/day, the Largest Capacity in Japan.
34


The user of deep seawater
Bade Haus…
Food, Water, etc.
1%
Sea Grapes
48%
Kuruma
Prawns
50%
35


Okinawa Prefectural Deep Sea Water Research Center and Business Park
Annual Output of DSW related Business: approx. 20 million USD
With 300 employees, which is one of the largest industry in Kumejima.
Food
4.1%
Water
3.2%
Soft Drinks
3.9%
Salt
1.9%
Nigari
0.3%
Cosmetics
23.9%
Kuruma
Prawns
47.7%
Food
13%
Other
27%
2.035
Billion Yen
Aquaculture
60%
Bade Haus
3.0%
Seaplants
8.7%
Fishery
0.4%
Prawn Hatchery
3.0%
36
Reference： 久米島海洋深層水複合利用基本調査 報告書



SATREPS

Subject : ***Development of Advanced Hybrid Ocean Thermal Energy Conversion (OTEC) Technology for Low Carbon Society and Sustainable Energy System: First Experimental Plant of Malaysia***

Term : April. 2019 – Mar. 2024 （5 years）

Funding : (JST)170Myen (JICA)300Myen（MoE, Malaysia）160Myen)

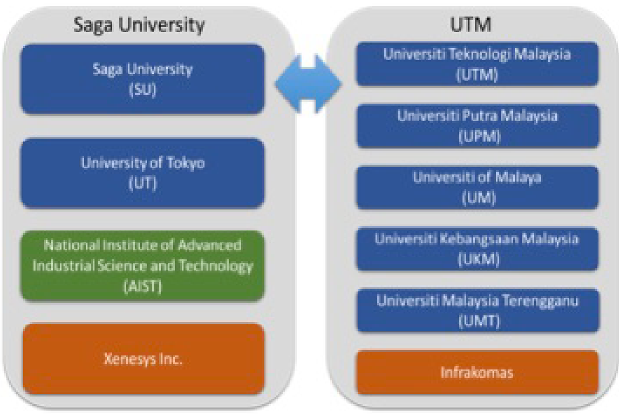
Overall goal: The implementation of combination of Hybrid OTEC (H-OTEC) and deep seawater application, so called "Malaysia Model", is commenced in Malaysia

Project purpose : Malaysia Model is established

<Research topics>

①H-OTEC pilot plant suitable for Malaysian environment is developed
②The optimum condition for H-OTEC in Malaysia is specified based on the experiment using pilot plant
③Suitable combination of DSW multiple use in Malaysia using H-OTEC is established
④Effect on the environment and CO2 emission is clarified
⑤The human capital on the OTEC technologies and on the DSW multiple use for business is developed

<Organization>



OTEC contribution to SDGs

IOES

39

Questions ?

IOES

40

Annex IV (Part 2) - Experiment of OTEC facility

The 1st on the site training on OTEC and DSW applications
3 December 2019, IOES Imari, Japan

Takeshi Yasunaga
Institute of Ocean Energy, Saga University, Japan

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SAGA UNIVERSITY

15kW OTEC facility

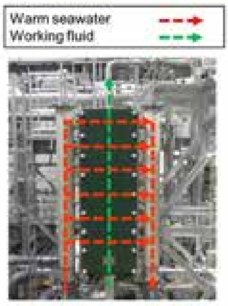
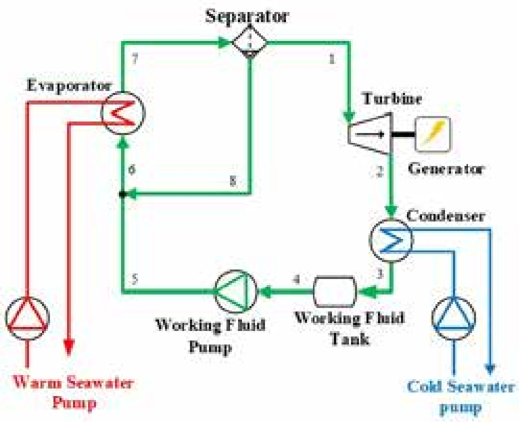
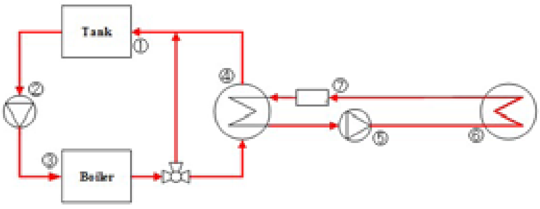


Plate type heat exchanger		
Material		Titanium
Length	mm	2,400
Width	mm	709
Thickness	mm	0.6
Breadth of flow channel	mm	2.8
Number of plate	-	48
Heat transfer area	m^2	87.4
Configuration of plate surface		Emboss

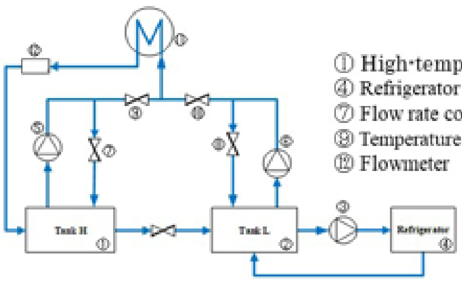


2

Heat source



① Warm source Tank ② Boiler circulation pump ③ Boiler
④ Warm water heater ⑤ Warm source pump ⑥ Evaporator
⑦ Flowmeter



① High-temperature tank ② Low-temperature tank ③ Refrigerator pump
④ Refrigerator ⑤ Cold source pump-No.1 ⑥ Cold source pump-No.2
⑦ Flow rate control valve-No.1 ⑧ Flow rate control valve-No.2
⑨ Temperature control valve-No.1 ⑩ Temperature control valve-No.2 ⑪ Condenser
⑫ Flowmeter

3

Annex IV (Part 3) - OTEC experimental data analysis

The 1st on the site training on OTEC and DSW applications
4 December 2019, IOES Imari, Japan

Takeshi Yasunaga
Institute of Ocean Energy, Saga University, Japan

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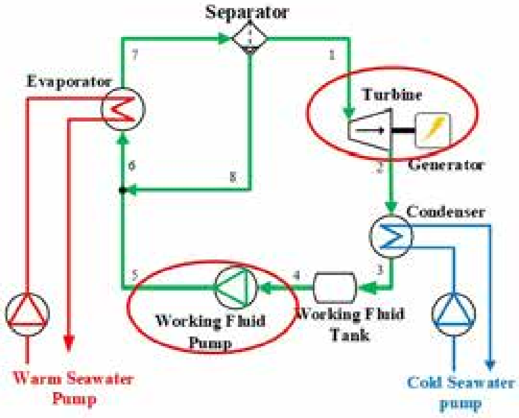
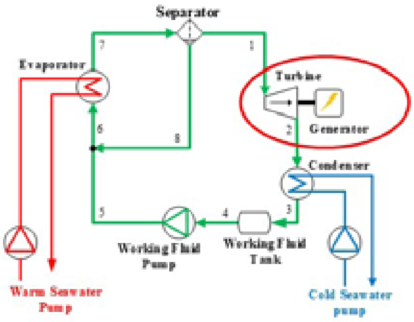
SAGA UNIVERSITY

Calculation of turbine and WF pump powers



2

Turbine power W_T



Actual turbine power W_T and turbine internal efficiency η_T

$$W_T = m_1(h_1 - h_2)$$
$$\eta_T = \frac{W_T}{W_{T,ideal}}$$
$$W_{T,ideal} = m_1(h_1 - h_2')$$
$$h_2' : s_2 = s_1 \ (isentropic\ change)$$

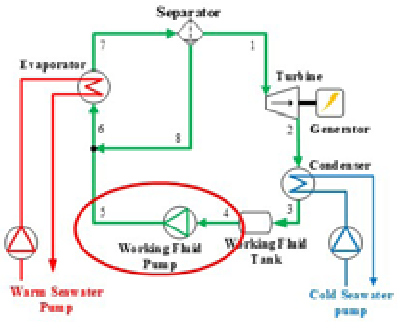
Since a pressure reduction valve is *<u>isenthalpic change</u>*, in the case of pressure reduction valve, the power is assumed and calculated:

- Assume the turbine outlet pressure is measured valve outlet pressure

$$s_2 = s_1 \ (isentropic\ change), P_2' = P_2 (measured\ value)$$
$$calculate\ h_2'\ using\ s_2\ and\ P_2$$
$$W_{T,assume} = m_1(h_1 - h_2')\eta_T$$

3

WF pump power W_P



Actual pump power W_P and Pump efficiency η_P

$$W_P = m_4(h_5 - h_4)$$

$$\eta_P = \frac{W_{P,ideal}}{W_P}$$

$$W_{P,ideal} = m_4(h_5' - h_4)$$

$$h_5' : s_5 = s_4 \ (isentropic\ change)$$

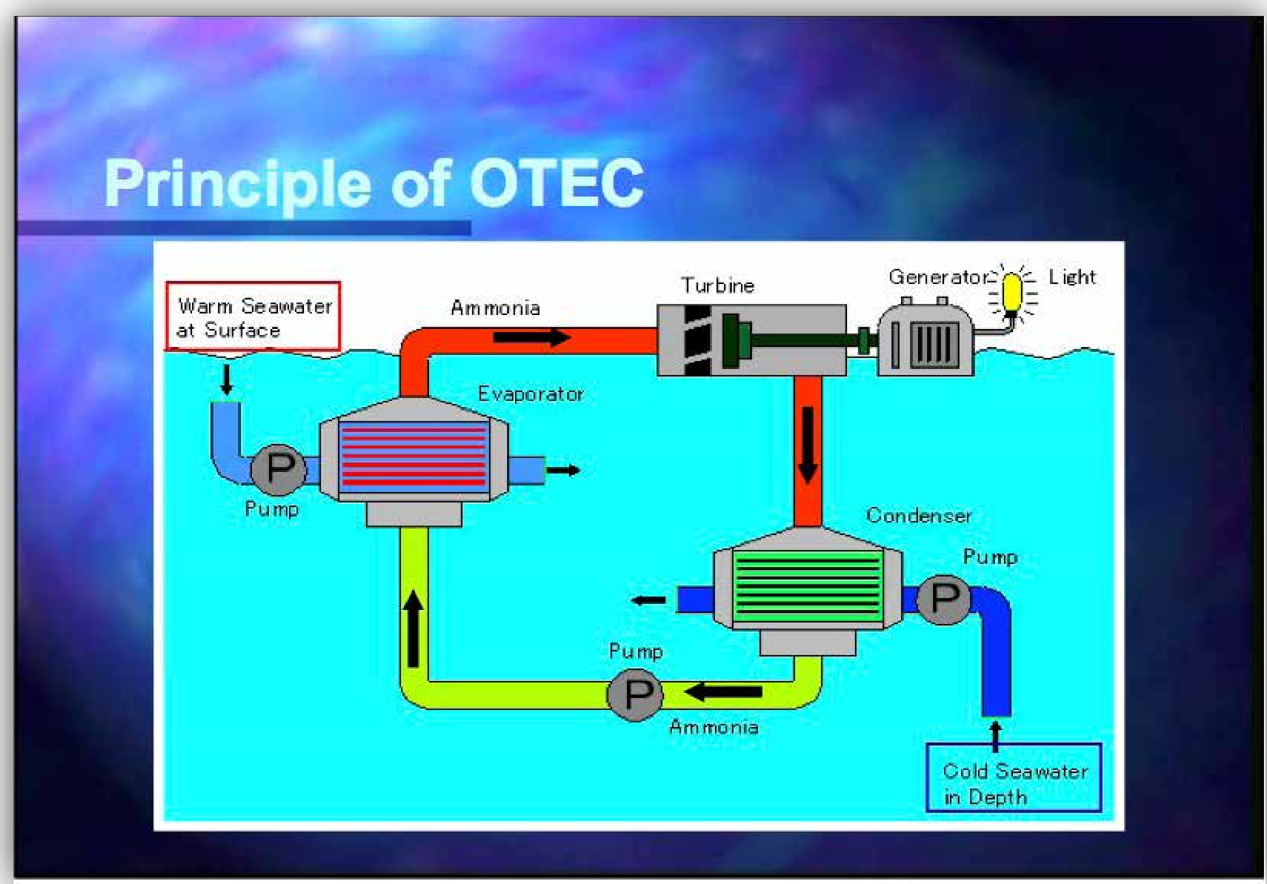
Since the change of the specific volume of liquid during the pump-up is negligible, W_P is usually simplified as follows:

$$v_5 \cong v_4 \ (isovolumetric\ change\ is\ negligible)$$

$$h_5 - h_4 = \int_4^5 v dP \cong v \int_4^5 dP = v_4 \ (P_5 - P_4)$$

4

ANNEX V PRESENTATION ON ADVANCED THERMODYNAMICS FOR OTEC

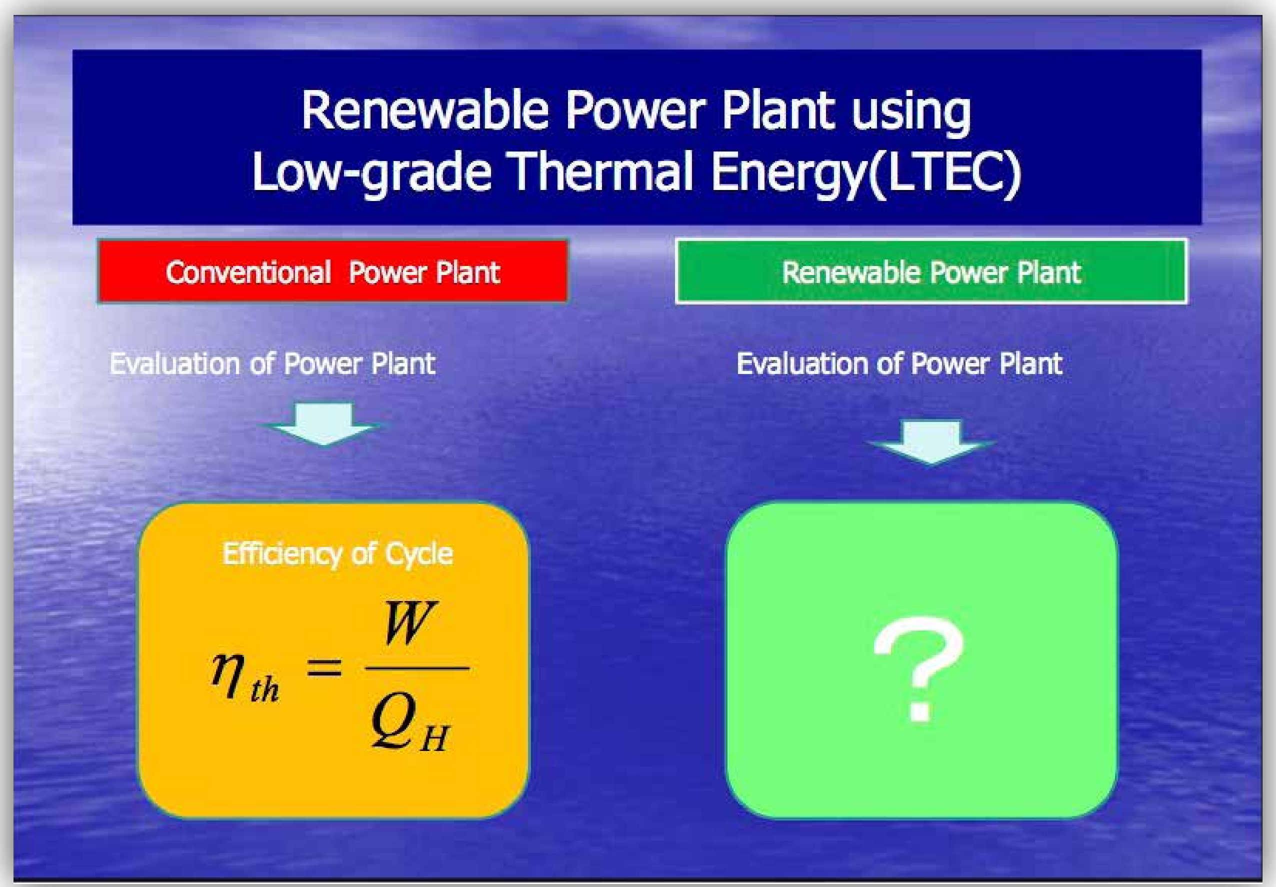


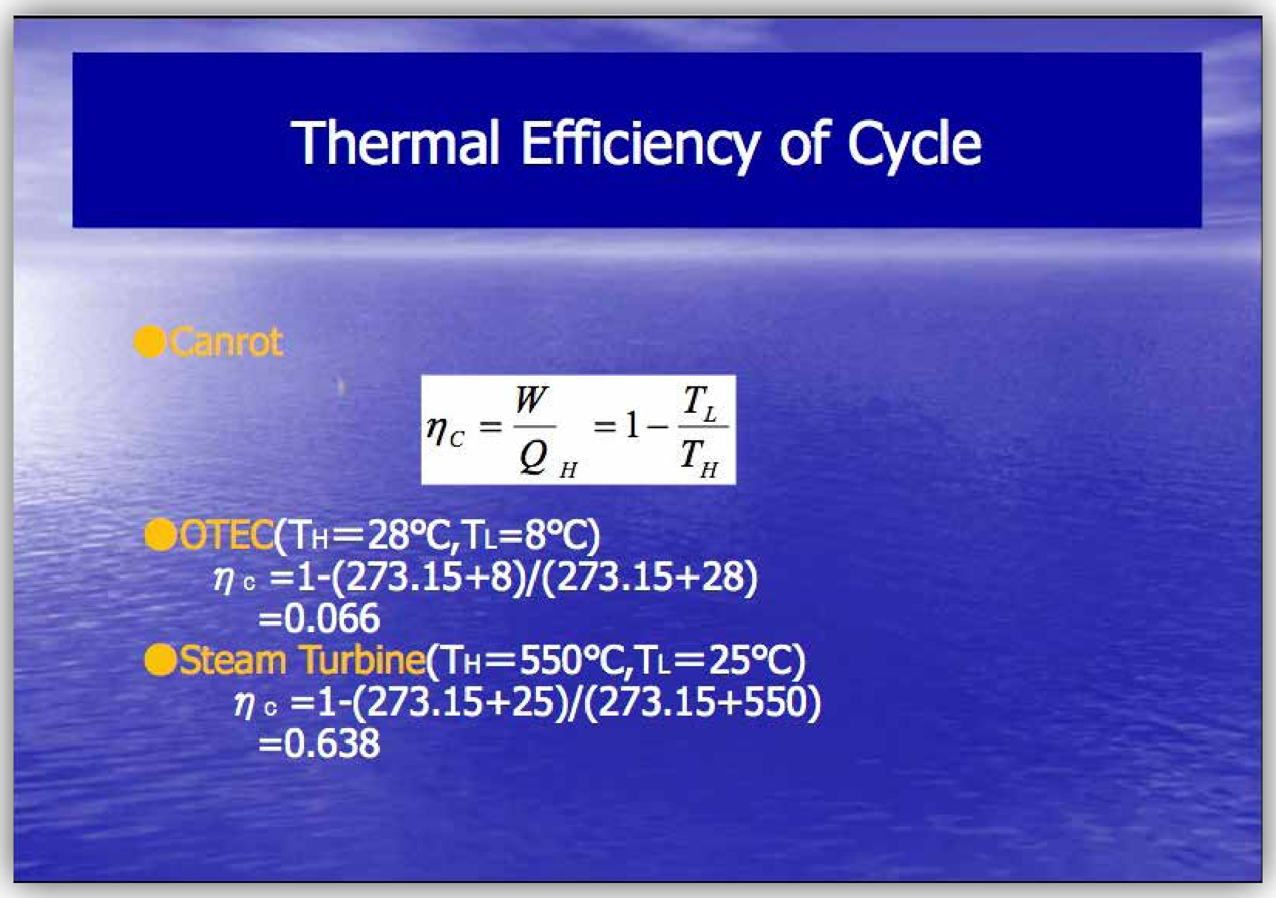
THE 1ST OTEC C/P TRAINING IN JAPAN SCHEDULE

	1/12/2019 - Sunday	2/12/2019 - Monday	3/12/2019 - Tuesday	4/12/2019 - Wednesday	5/12/2019 - Thursday
			Hotel Pickup	Hotel Pickup	6:00 Highway Bus to FUK
8:00		8:10 Arrival at FU	8:00 to 12:00 IOES OTEC experomental plant Set-up	8:00 to 12:00 OTEC data analysis IOES Imari, Seawater Intake facility briefing (1 hour)	8:00 Arrival at FUK
8:30		Move to FUK Domestic Airport			
9:00					9:25 JTA053 to OKA
9:30		9:33 Highway Bus to Imar			
10:00					
10:30					
11:00					11:15 Arrive at Naha Airport (OKA)
11:30		11:53 Arrival at Imari Station Saga Univ. Bus pick up			
12:00		Lunch (Lunch Box	Lunch (Lunch Box	Lunch (Lunch Box	Lunch at Airport
12:30					
13:00	21:05 TG418 to Bangkok (BKK) KUL-BKK 22:10 Arrival at BKK +01:00 TG648 to Fukuoka(FUK) BKK-FUK	13:00 Guidance	13:00 to 18:00 IOES OTEC experimental plant operation	13:00 to 18:00 OTEC data analysis Xenesys Inc. HEx manufacturing plant site visit and briefing Dr. Yeong (Project6) and Dr. Fadhil (Project7) had a meeting/discussion with Dr. Shin Hirayama (2 hours)	
13:30		14:00 to 17:00 IOES Facility Tour			13:40 JTA211 to UEO
14:00					14:20 Arrival at Kumejima(UEO)
14:30					
15:00					Hotel Check In
15:30					Kumejima Schedule Guidance Meeting @ Resort Hotel Kume Island
16:00					
16:30					16:30 Courtesy Visit to Town Mayor, Mr. Haruo Ohta
17:00		17:00 -19:00 Welcome Reception			
17:30					
18:00			Dinner (Free Choice)	Dinner (Free Choice)	Dinner (Free Choice)
18:30					
19:00					
19:30					
20:00					
HOTEL	Flight	Central Hotel Imari			

ANNEX I OVERALL TRAINING SCHEDULE

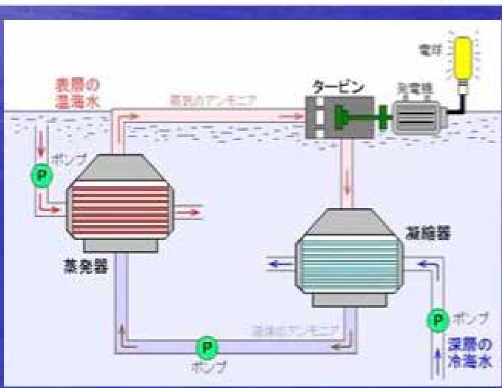
6/12/2019 - Friday	7/12/2019 - Saturday	8/12/2019 - Sunday	9/12/2019 - Monday	10/12/2019 - Tuesday	11/12/2019 - Wednesday
	8:45 Hotel Pickup		8:45 Hotel Pickup		8:30 Check out
9:15 Hotel Pickup	9:00 to 12:00 Session 1 - Okinawa Deep Seawater Research Centre		9:00 to 12:00 Session 3 - Okinawa Deep Seawater Research Centre Coral Conservation site visit (1 hour) Lecture by Kakuma Sensei (Former director of the Okinawa Deep Seawater Research Centre) (1 hour)	Hotel Check Out Resort Hotel Kume Island	Move to FUK International Airport
9:30 Cosmetics Company Visit					
10:00 Oyster Farm Visit				10:00 Hotel Pickup	
10:30 Water Bottling Company Visit					
11:05 Prawn Farm Visit					
11:30 Deep Seawater Spa Facility Visit		11:45 Hotel Pickup		11:30 RAC876 to OKA Depart Kumejima	11:40 TG649 to BKK
Lunch (Namiji Restaurant)	Lunch (Fishery Coopera-tive)	Lunch (Your Choice at Convinience Store)	Lunch (Your Choice at A-Coop Store)	12:05 Arrive at OKA	
				Lunch at Airport	16:45 TG417 to KUL
13:00 Deep Seawater Research Centre Visit	13:00 to 17:00 Session 2 - Okinawa Deep Seawater Research Centre	13:00 Optional Kumejima Sightseeing (Miifuga Rock, Gushikawa Castle, Ghost Slope, Souvineer Shopping, etc.) Silk Pavilion Costs 200JPY	13:00 to 17:00 Session 4 - Okinawa Deep Seawater Research Centre	13:10 JTA054 to FUK	
13:30 OTEC Project Introduction					
14:00 OTEC Facility Tour					
14:30 Cold Soil Agriculture Visit					
15:15 Kumejima Sightseeing (Tunaha Mountain, Yachimun Gallery, Uegusuku Castle, Hiyajo Cliff)				14:55 Arrival at FUK	
				Move to Hakata	15:40 Arrival at BKK
		17:00 Hotel Return		16:00-17:30 Wrap-up Meeeting	
					16:45 TG417 to KUL
17:00 Hotel Return	17:00 Hotel Return	17:00 Optional Bade Haus Visit ~1100JPY (Dinner Available)	17:00 Hotel Return		
	Dinner (Free Choice)		Dinner (Free Choice		
18:30 Welcome Dinner @ Kameyoshi Restaurant		Dinner (Free Choice			
					19:55 Arrival at KUL
Kume Island Hotel				Confort Hotel Hakata	n/a


Renewable Power Plant using
Low-grade Thermal Energy(LTEC)
Conventional Power Plant
Renewable Power Plant
Evaluation of Power Plant
Evaluation of Power Plant
Efficiency of Cycle
$\eta_{th} = \frac{W}{Q_H}$
?


Thermal Efficiency of Cycle
●Canrot
$\eta_C = \frac{W}{Q_H} = 1 - \frac{T_L}{T_H}$
●OTEC(T_H=28°C, T_L=8°C)
η_c =1-(273.15+8)/(273.15+28)
=0.066
●Steam Turbine(T_H=550°C, T_L=25°C)
η_c =1-(273.15+25)/(273.15+550)
=0.638

Efficiency of Net power

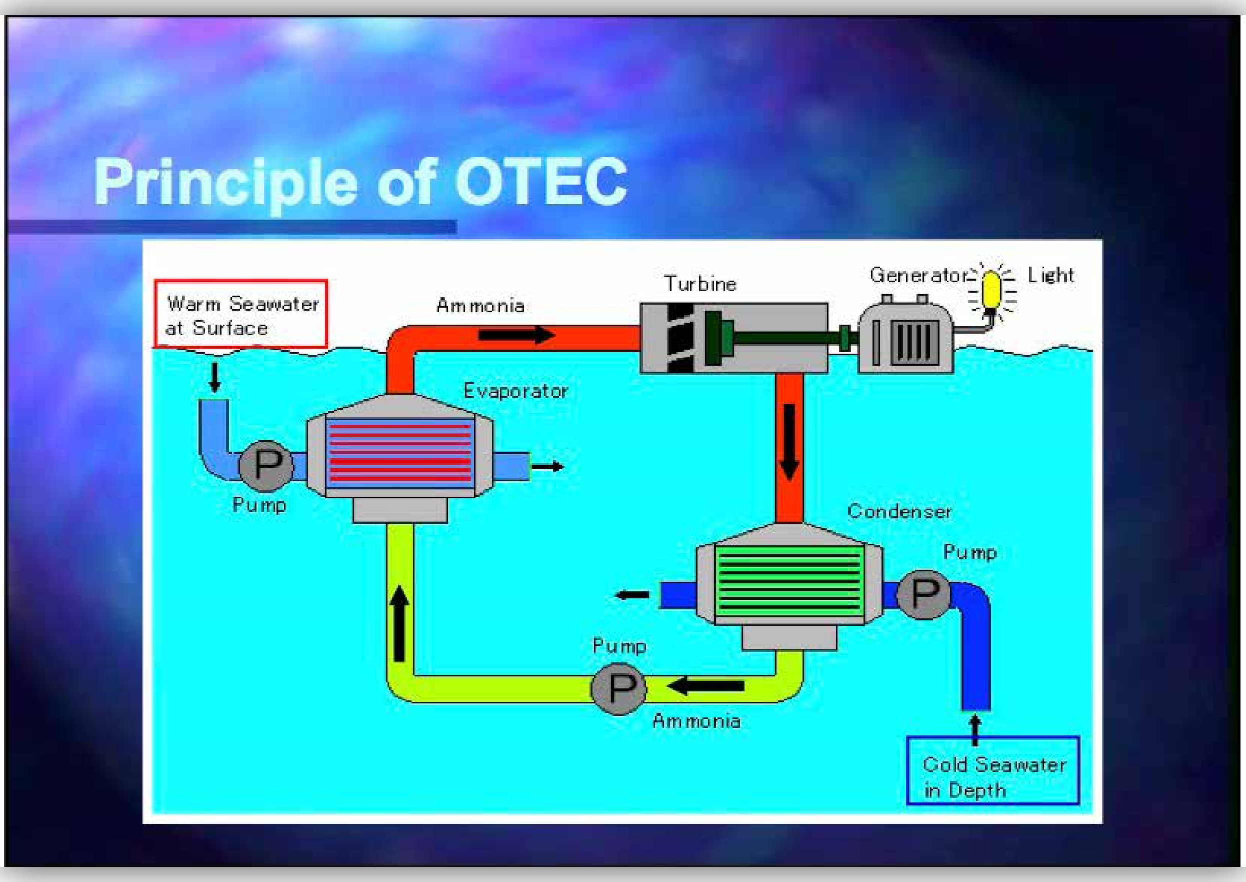
$$\eta_{net} = \frac{W_{net}}{W_G} = \frac{W_G - (W_{WS} + W_{CS} + W_{WF})}{W_G}$$

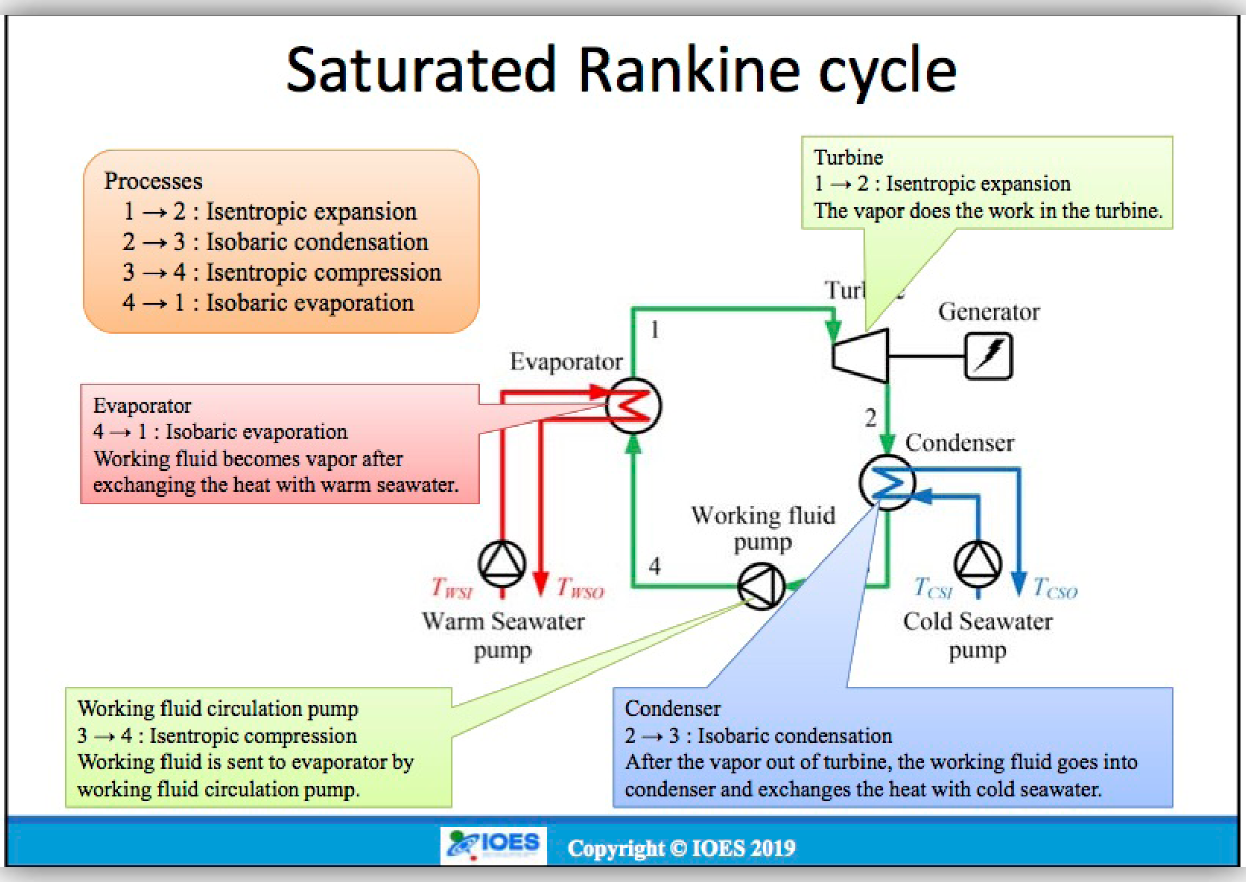


Efficiency of Net Power

$$\eta_{net} = \frac{W_{net}}{W_G} = \frac{W_G - (W_{WS} + W_{CS} + W_{WF})}{W_G}$$

- Conventional Power Plant
  90%～95%
- OTEC
  50%～80%


Principle of OTEC
Warm Seawater at Surface
Ammonia
Turbine
Generator
Light
Evaporator
Pump
Condenser
Pump
Pump
Ammonia
Cold Seawater in Depth


Saturated Rankine cycle
Processes
1 → 2 : Isentropic expansion
2 → 3 : Isobaric condensation
3 → 4 : Isentropic compression
4 → 1 : Isobaric evaporation
Turbine
1 → 2 : Isentropic expansion
The vapor does the work in the turbine.
Generator
Evaporator
Evaporator
4 → 1 : Isobaric evaporation
Working fluid becomes vapor after exchanging the heat with warm seawater.
Condenser
Working fluid pump
Warm Seawater pump
Cold Seawater pump
Working fluid circulation pump
3 → 4 : Isentropic compression
Working fluid is sent to evaporator by working fluid circulation pump.
Condenser
2 → 3 : Isobaric condensation
After the vapor out of turbine, the working fluid goes into condenser and exchanges the heat with cold seawater.
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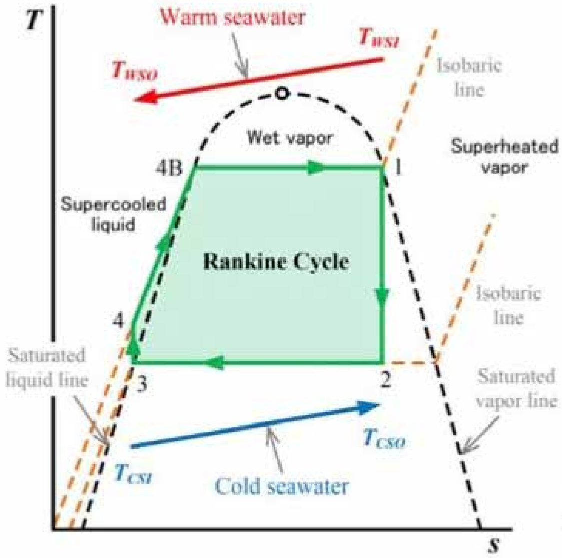
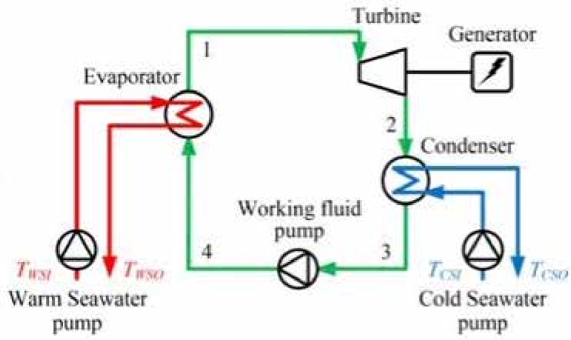
Saturated Rankine cycle



T-s diagram of Rankine cycle

Processes

1 → 2 : Isentropic expansion
2 → 3 : Isobaric condensation
3 → 4 : Isentropic compression
4 → 1 : Isobaric evaporation



Rankine cycle flow

Equations 1/3

Turbine power W_T

$$W_T = m_{WF}\,(h_1 - h_2)$$

Working fluid pumping power W_{PWF}

$$W_{PWF} = m_{WF}\,(h_4 - h_3)$$

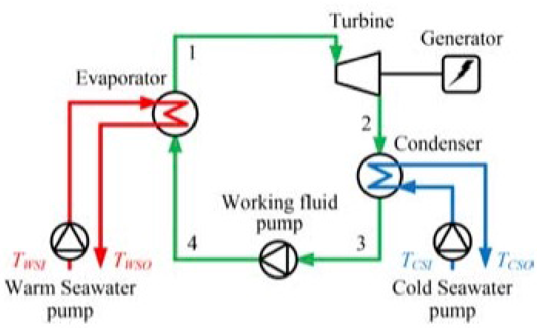
Power output W

$$W = W_T - W_{PWF} = m_{WF}\,[(h_1 - h_2) - (h_4 - h_3)]$$

m_{WF} : Working fluid flow rate [kg/s]
h : Specific enthalpy [kJ/kg]

Processes

1 → 2 : Isentropic expansion
2 → 3 : Isobaric condensation
3 → 4 : Isentropic compression
4 → 1 : Isobaric evaporation



Rankine cycle flow

Equations 2/3

Power output W

$$W = W_T - W_{PWF}$$
$$= m_{WF}\,[(h_1 - h_2) - (h_4 - h_3)]$$

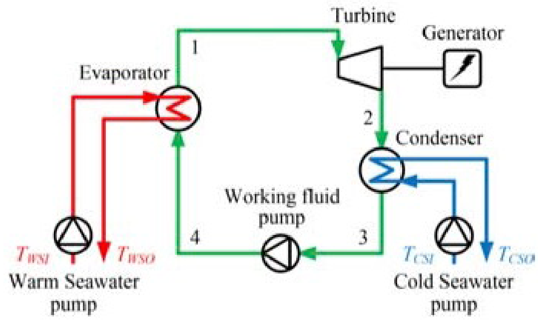
Heat flow rate of evaporator Q_E

$$Q_E = m_{WF}\,(h_1 - h_4)$$

Thermal efficiency of cycle η_{th}

$$\eta_{th} = \frac{W}{Q_E} = \frac{m_{WF}\,[(h_1 - h_2) - (h_4 - h_3)]}{m_{WF}\,(h_1 - h_4)} = \frac{(h_1 - h_2) - (h_4 - h_3)}{(h_1 - h_4)}$$

Processes
- $1 \rightarrow 2$: Isentropic expansion
- $2 \rightarrow 3$: Isobaric condensation
- $3 \rightarrow 4$: Isentropic compression
- $4 \rightarrow 1$: Isobaric evaporation



Rankine cycle flow

Equations 3/3

Heat flow rate of evaporator Q_E

$$Q_E = m_{WF}\,(h_1 - h_4)$$

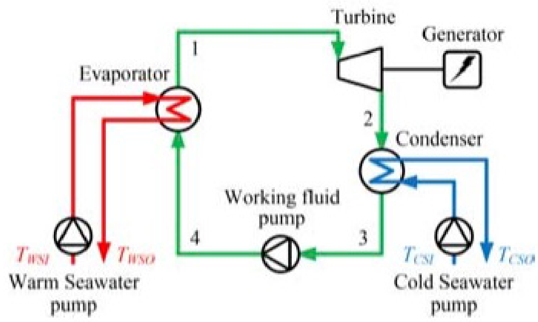
Heat flow rate of condenser Q_C

$$Q_C = m_{WF}\,(h_2 - h_3)$$

Thermal efficiency of cycle η_{th}

$$\eta_{th} = \frac{W}{Q_E} = \frac{(h_1 - h_2) - (h_4 - h_3)}{(h_1 - h_4)} = \frac{(h_1 - h_4) - (h_2 - h_3)}{(h_1 - h_4)} = 1 - \frac{Q_C}{Q_E}$$

Processes
- $1 \rightarrow 2$: Isentropic expansion
- $2 \rightarrow 3$: Isobaric condensation
- $3 \rightarrow 4$: Isentropic compression
- $4 \rightarrow 1$: Isobaric evaporation



Rankine cycle flow

Thermal property at each point

	T [℃]	P [MPa]	S [kJ/kgK]	h [kJ/kg]
1				
2				?
3				
4B				
4	–			?
2V				

How to calculate on h2

$h2 = h3 + x(h2v - h3)$

$s2 = s3 + x(s2v - s3)$

$x = (h_2 - h_3) / (h_2v - h3)$

$x = (s_2 - s_3) / (s_2v - s3)$

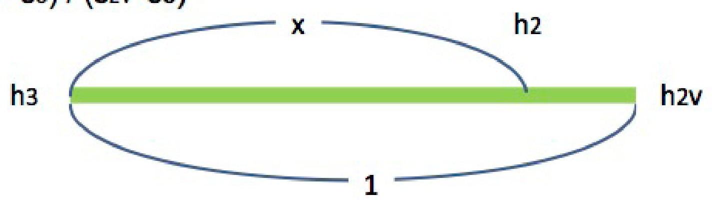
x=x

X: Dryness

$x = (s_2 - s_3) / (s_{2v} - s_3)$

s2=s1

$= (s_1 - s_3) / (s_{2v} - s_3)$



How to calculate on h_4

$h_4 = h_3 + v_3(P_4 - P_3)$

Working Fluid Pump $= h_4 - h_3 = v_3(P_4 - P_3)$

Specific Volume=1/density

$V_3 = 1/\rho_3$

Pa=N/m^2
J=N・m
N=J/m

m^3/kg×J/m^3=J/kg
⇒ kJ/kg

Example.

h_3=103.8kJ/kg
V_3=0.001(m^3/kg)
P_3=600kPa, P_4=900kPa

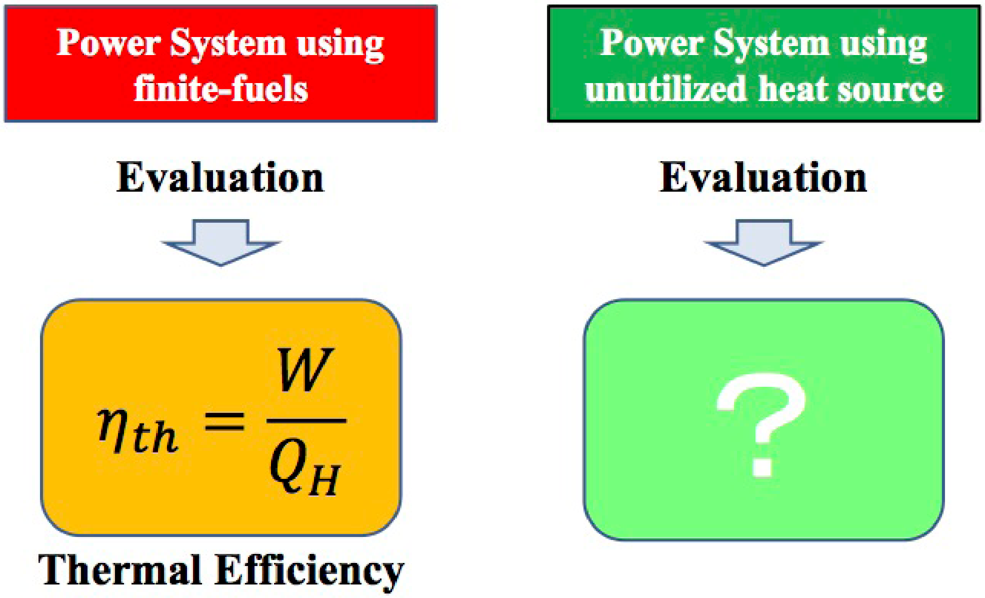
Why "×1000" ?
kPa ⇒ Pa

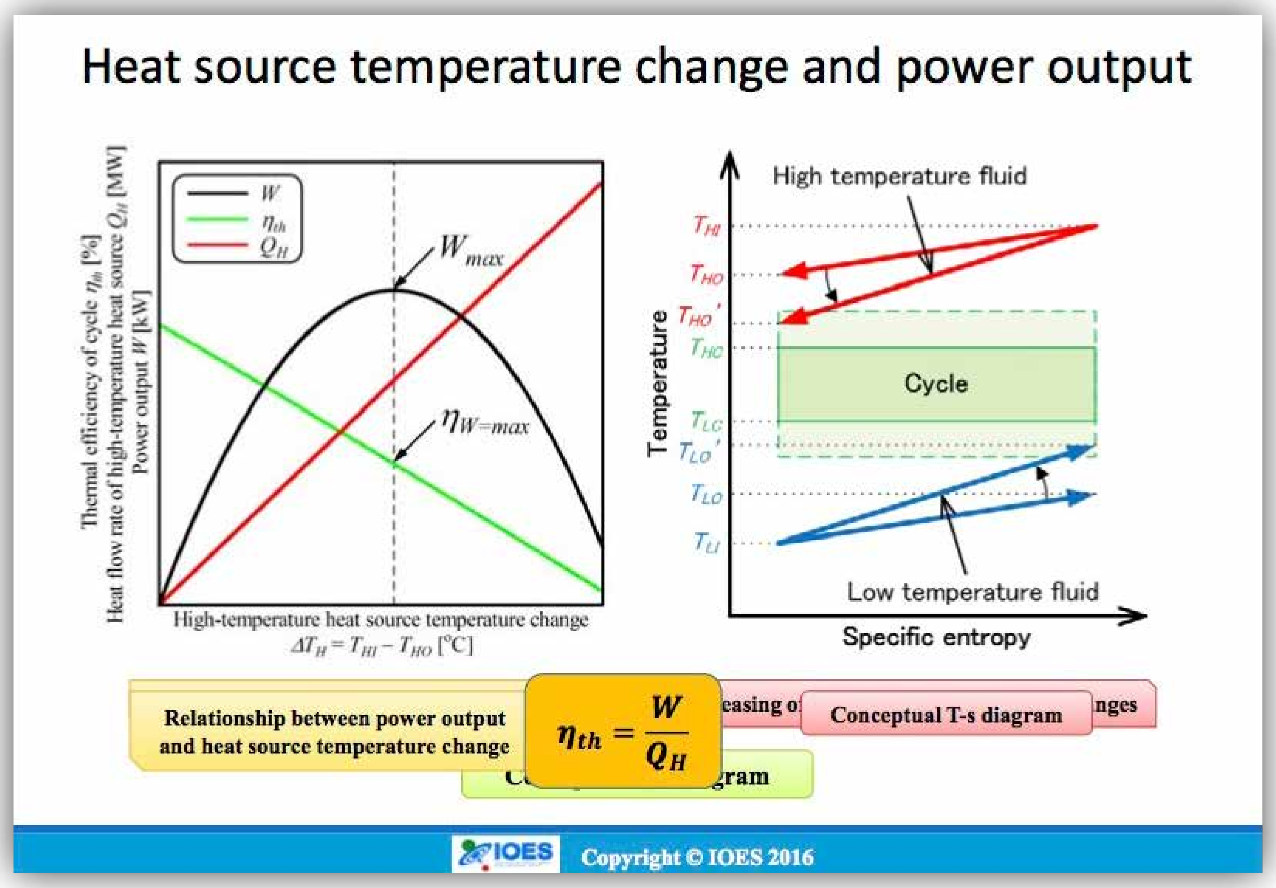
Working Fluid Pump$= v_3(P_4 - P_3)$
=0.001(900×1000−600×1000)/1000
=0.3kJ/kg

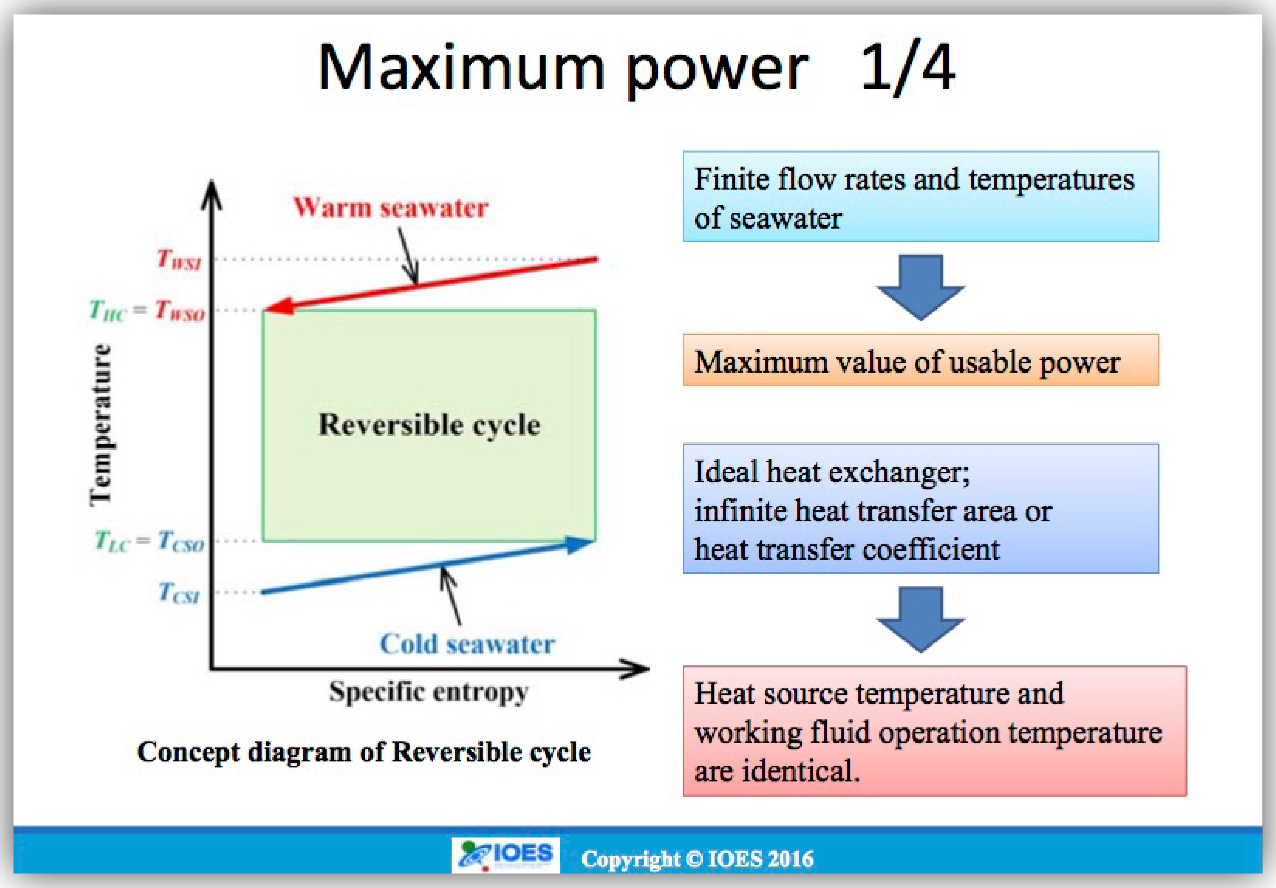
Why "/1000" ?
J/kg ⇒ kJ/kg

$h_4 = h_3 + v_3(P_4 - P_3)$=103.8+0.3=104.1kJ/kg

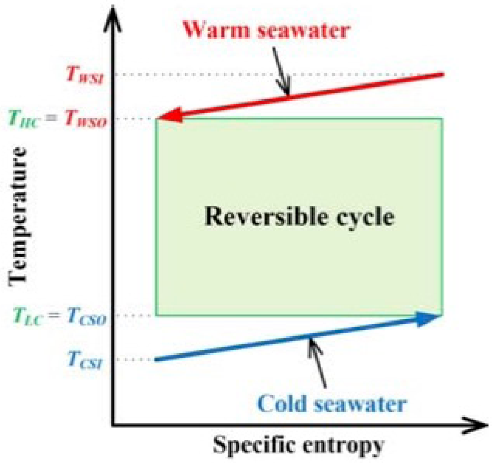
Renewable Power System using Ocean Thermal Energy Conversion




Heat source temperature change and power output
W
ηth
QH
W max
ηW=max
Thermal efficiency of cycle ηth [%]
Heat flow rate of high-temperature heat source QH [MW]
Power output W [kW]
High-temperature heat source temperature change
ΔTH = THI − THO [°C]
High temperature fluid
Low temperature fluid
Temperature
Specific entropy
Cycle
THI
THO
THO'
THC
TLC
TLO'
TLO
TLI
Relationship between power output
and heat source temperature change
ηth = W / QH
Conceptual T-s diagram
Copyright © IOES 2016


Maximum power 1/4
Warm seawater
TWSI
THC = TWSO
Reversible cycle
TLC = TCSO
TCSI
Cold seawater
Temperature
Specific entropy
Concept diagram of Reversible cycle
Finite flow rates and temperatures of seawater
Maximum value of usable power
Ideal heat exchanger;
infinite heat transfer area or
heat transfer coefficient
Heat source temperature and
working fluid operation temperature
are identical.
Copyright © IOES 2016

Maximum power 2/4



C_H : Heat capacity flow rate for warm seawater

C_L : Heat capacity flow rate for cold seawater

C = specific heat × flow rate

Heat flow rate from warm seawater Q_{WS}

$$Q_{WS} = C_{WS}\,(T_{WSI} - T_{WSO})$$

Heat flow rate to cold seawater Q_{CS}

$$Q_{CS} = C_{CS}\,(T_{CSO} - T_{CSI})$$

Power output of Reversible cycle W

$$W = Q_{WS} - Q_{CS}$$

Because of the reversible cycle, the entropy generation is zero,

$$\oint ds = \frac{Q_{WS}}{T_{HC}} - \frac{Q_{CS}}{T_{LC}} = \frac{Q_{WS}}{T_{WSO}} - \frac{Q_{CS}}{T_{CSO}} = 0$$

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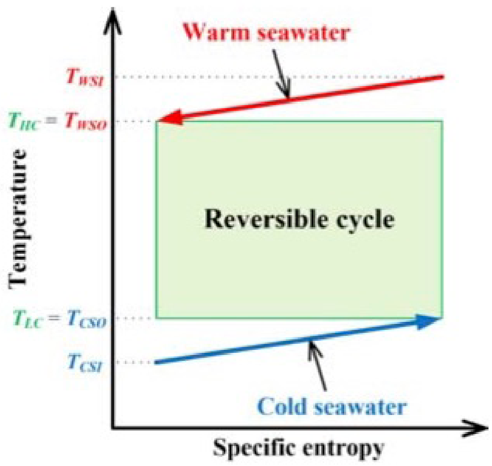
Maximum power 3/4



C_H : Heat capacity flow rate for warm seawater

C_L : Heat capacity flow rate for cold seawater

C = specific heat × flow rate

Power output of Reversible cycle W

$$W = Q_{WS} - Q_{CS}$$

$$\oint ds = \frac{Q_{WS}}{T_{WSO}} - \frac{Q_{CS}}{T_{CSO}} = 0$$

The maximum power W_m can be introduced by differentiation of the power output W over the warm and cold seawaters discharge temperatures T_{WSO}, T_{CSO} as follows,

$$\frac{\partial W}{\partial T_{WSO}} = 0 \qquad \frac{\partial W}{\partial T_{CSO}} = 0$$

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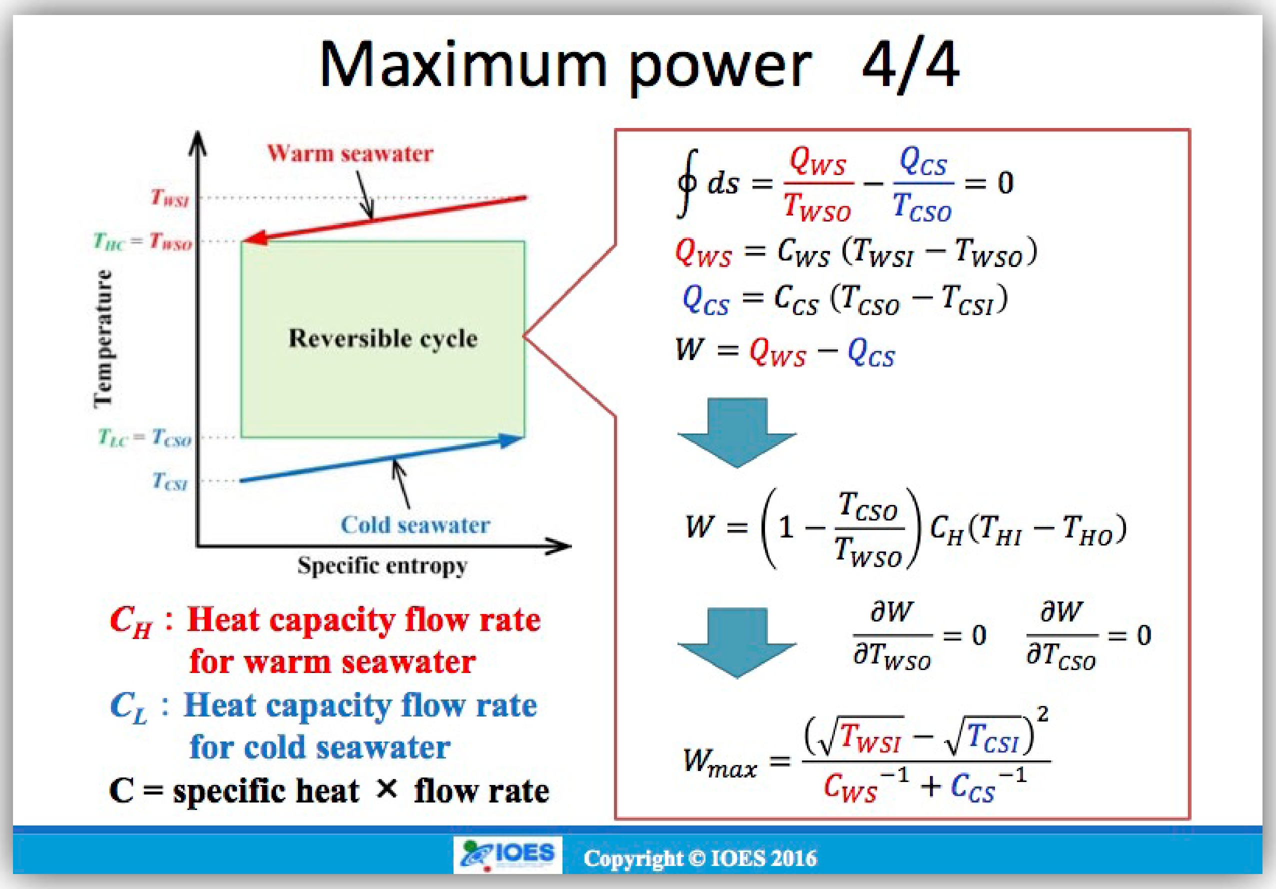
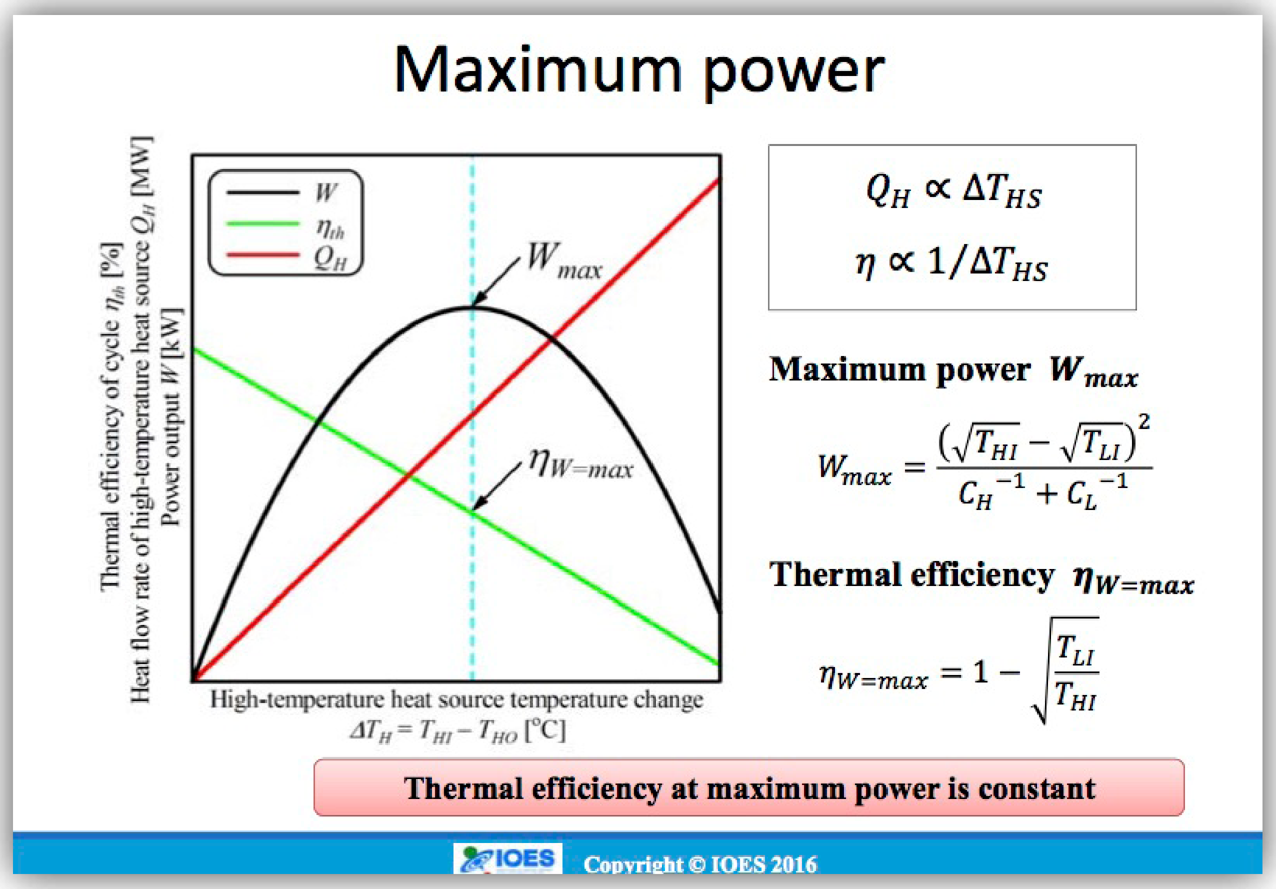
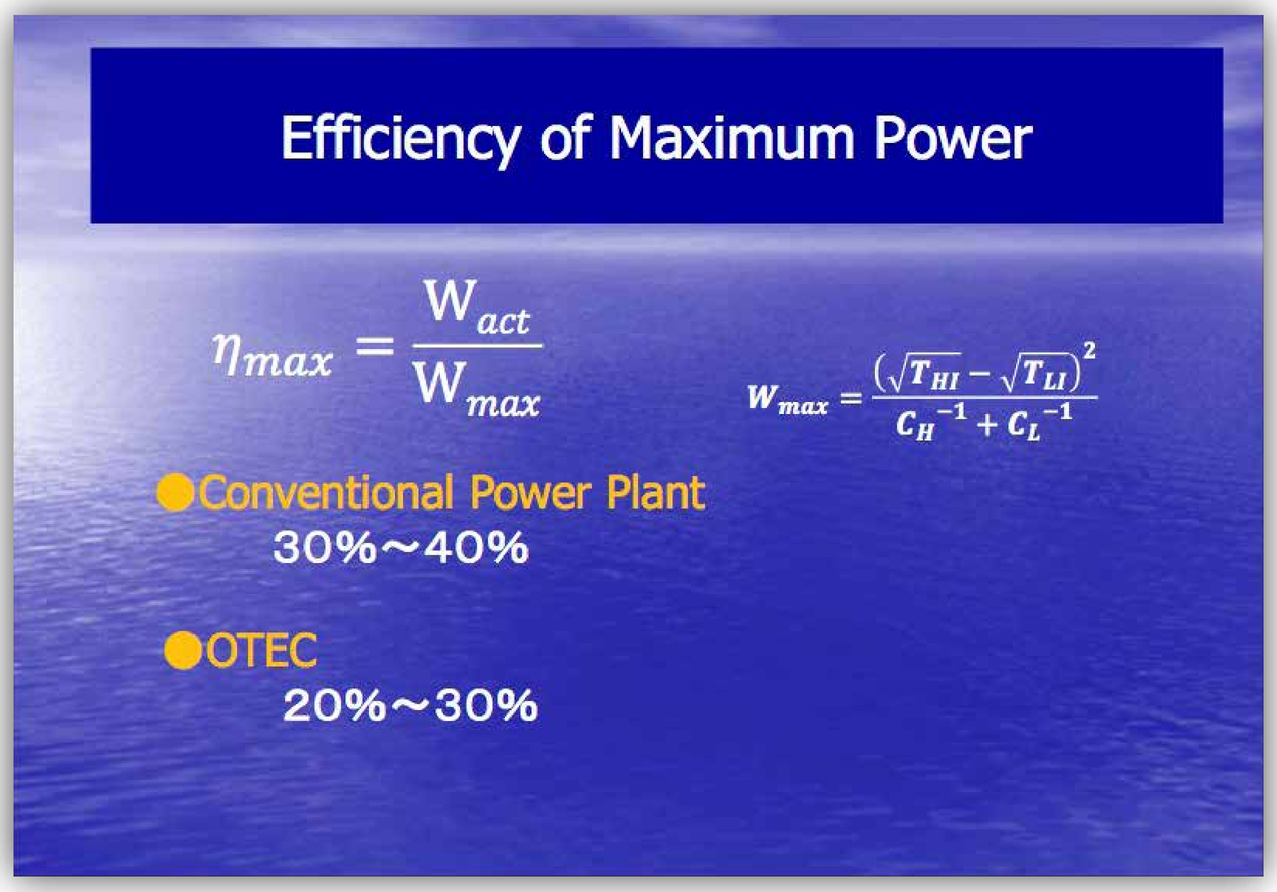
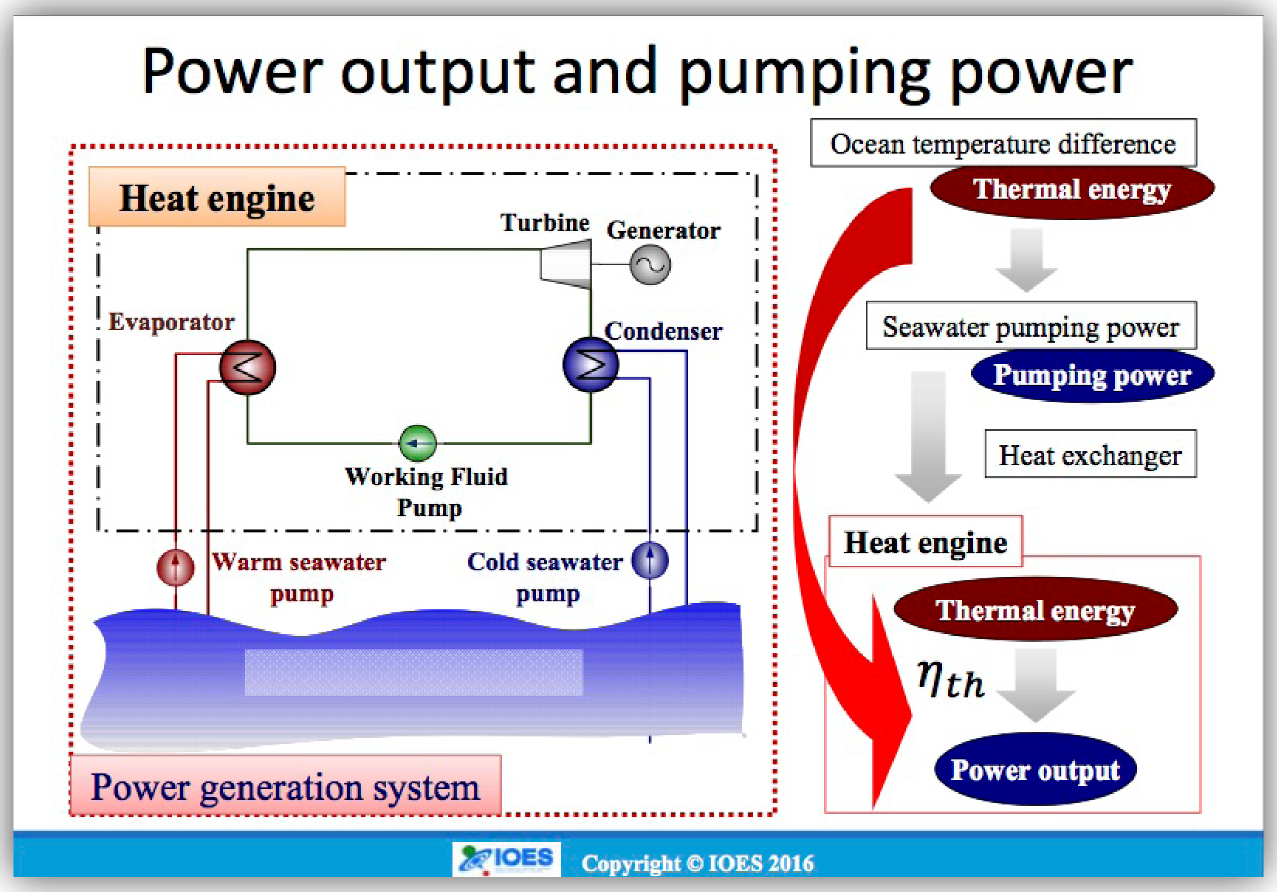

Maximum power 4/4
Warm seawater
T_{WSI}
$T_{HC} = T_{WSO}$
Temperature
Reversible cycle
$T_{LC} = T_{CSO}$
T_{CSI}
Cold seawater
Specific entropy
C_H : Heat capacity flow rate for warm seawater
C_L : Heat capacity flow rate for cold seawater
C = specific heat × flow rate
$\oint ds = \frac{Q_{WS}}{T_{WSO}} - \frac{Q_{CS}}{T_{CSO}} = 0$
$Q_{WS} = C_{WS}(T_{WSI} - T_{WSO})$
$Q_{CS} = C_{CS}(T_{CSO} - T_{CSI})$
$W = Q_{WS} - Q_{CS}$
$W = \left(1 - \frac{T_{CSO}}{T_{WSO}}\right) C_H (T_{HI} - T_{HO})$
$\frac{\partial W}{\partial T_{WSO}} = 0 \quad \frac{\partial W}{\partial T_{CSO}} = 0$
$W_{max} = \frac{\left(\sqrt{T_{WSI}} - \sqrt{T_{CSI}}\right)^2}{C_{WS}^{-1} + C_{CS}^{-1}}$
Copyright © IOES 2016


Maximum power
W
η_{th}
Q_H
W_{max}
$\eta_{W=max}$
Thermal efficiency of cycle η_{th} [%]
Heat flow rate of high-temperature heat source Q_H [MW]
Power output W [kW]
High-temperature heat source temperature change
$\Delta T_H = T_{HI} - T_{HO}$ [°C]
$Q_H \propto \Delta T_{HS}$
$\eta \propto 1/\Delta T_{HS}$
Maximum power W_{max}
$W_{max} = \frac{\left(\sqrt{T_{HI}} - \sqrt{T_{LI}}\right)^2}{C_H^{-1} + C_L^{-1}}$
Thermal efficiency $\eta_{W=max}$
$\eta_{W=max} = 1 - \sqrt{\frac{T_{LI}}{T_{HI}}}$
Thermal efficiency at maximum power is constant
Copyright © IOES 2016


Efficiency of Maximum Power
$\eta_{max} = \frac{W_{act}}{W_{max}}$
$W_{max} = \frac{(\sqrt{T_{HI}} - \sqrt{T_{LI}})^2}{C_H^{-1} + C_L^{-1}}$
●Conventional Power Plant
30%～40%
●OTEC
20%～30%


Power output and pumping power
Heat engine
Turbine
Generator
Evaporator
Condenser
Working Fluid Pump
Warm seawater pump
Cold seawater pump
Power generation system
Ocean temperature difference
Thermal energy
Seawater pumping power
Pumping power
Heat exchanger
Heat engine
Thermal energy
η_{th}
Power output
IOES
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Net power of OTEC system

Net power W_{net}

$$W_{net} = (W_T - W_{P,WF}) - (W_{P,WS} + W_{P,CS})$$

[net power] = [Power output] – [Seawater pumping power]

$$W_{P,WS} = \frac{m_{WS}\,\Delta P_{WS}}{\rho_{WS}\,\eta_{P,WS}}$$

$$W_{P,CS} = \frac{m_{CS}\,\Delta P_{CS}}{\rho_{CS}\,\eta_{P,CS}}$$

Seawater pumping power

$$W_{P,WS} = R_{WS}\,C_{WS}{}^{n+1}$$

$$W_{P,CS} = R_{CS}\,C_{CS}{}^{n+1}$$

$$W_{net} = W - R_{WS}\,C_{WS}{}^{n+1} - R_{CS}\,C_{CS}{}^{n+1}$$

Pressure loss ΔP

$$\Delta P_{WS} = r_{WS}\,m_{WS}{}^{n}$$

$$\Delta P_{CS} = r_{CS}\,m_{CS}{}^{n}$$

n : exponent, a turbulent flow example ($n = 1.8$)

r : flow resistance $\quad$ R : modified flow resistance

Maximum net power

Net power under the condition of maximum power

$$W_{net} = \frac{\Delta T}{C_{WS}{}^{-1} + C_{CS}{}^{-1}} - R_{WS}\,C_{WS}{}^{n+1} - R_{CS}\,C_{CS}{}^{n+1}$$

$$\Delta T = \left(\sqrt{T_{WSI}} - \sqrt{T_{CSI}}\right)^2$$

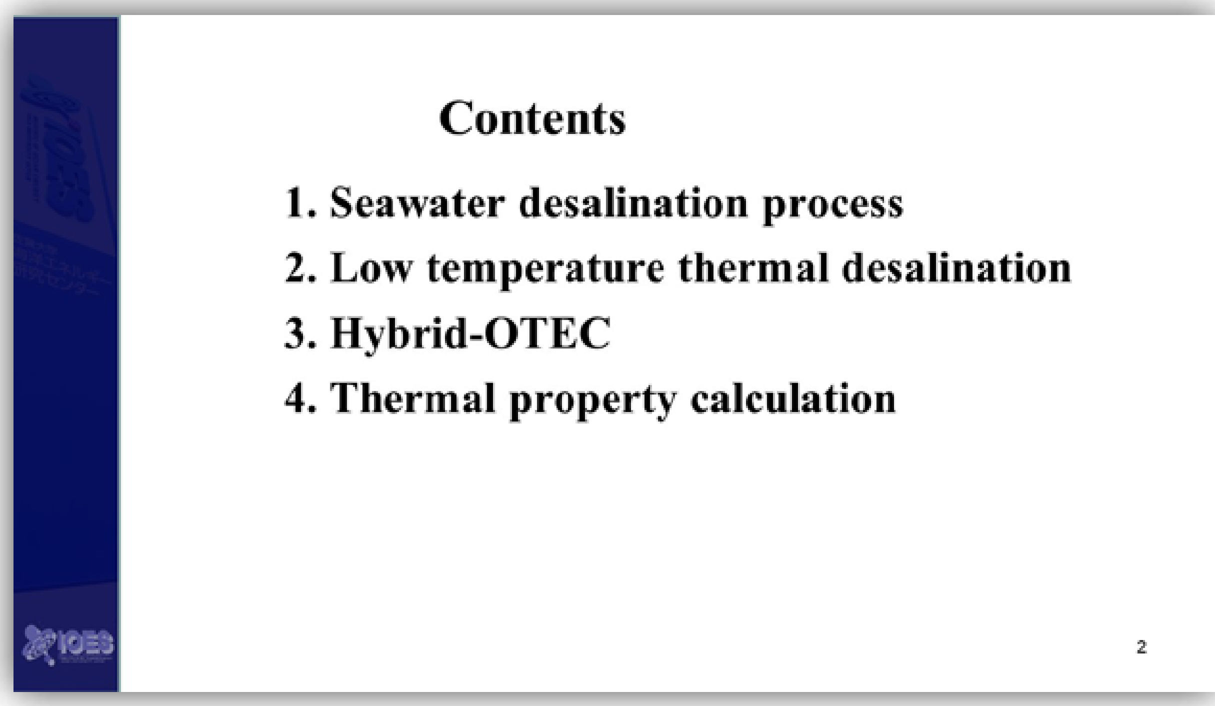
Maximum net power ($\partial W_{net}/\partial C_{WS} = 0$, $\partial W_{net}/\partial C_{CS} = 0$)

$$W_{net,m} = n\left(\frac{\Delta T}{n+1}\right)^{(n+1)/n}\left[R_{WS}{}^{1/(n+2)} + R_{CS}{}^{1/(n+2)}\right]^{-(n+2)/n}$$

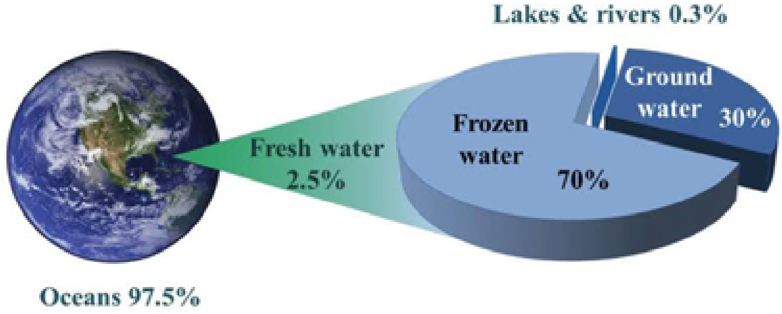
$$C_{WS,opt} = \left[\frac{\Delta T}{(n+1)R_{WS}(b+1)^2}\right]^{1/n} \qquad C_{CS,opt} = \left[\frac{\Delta T}{(n+1)R_{CS}(b^{-1}+1)^2}\right]^{1/n}$$

$$b = \left(\frac{R_{CS}}{R_{WS}}\right)^{1/(n+2)}$$

ANNEX VI PRESENTATION ON SEAWATER DESALINATION AND H-OTEC



Why seawater desalination ?

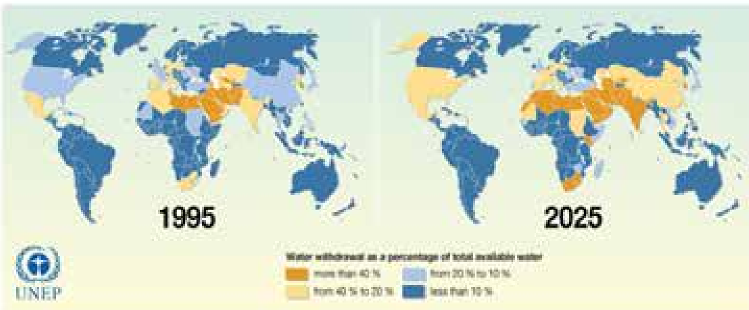


- 75% of Earth's surface is covered by water
- Fresh water is only 2.5%
- 70% of the fresh water is the Frozen water (ice)

Only less than 1% is available drinkable water

3

Why seawater desalination ?



Based upon the UN Medium Population Projections of 1998,

2.8 billion people in 48 countries will face water stress, or scarcity conditions by 2025.

40 are in West Asia, North Africa or sub-Saharan Africa.

Over the next two decades, population increases and growing demands are projected to push all the West Asian countries into water scarcity conditions.

By 2050, the number of countries facing water stress or scarcity could rise to 54
It reprsents a combined population of 4 billion people - about 40% of the projected global population (Gardner-Outlaw and Engleman, 1997; UNFPA, 1997).

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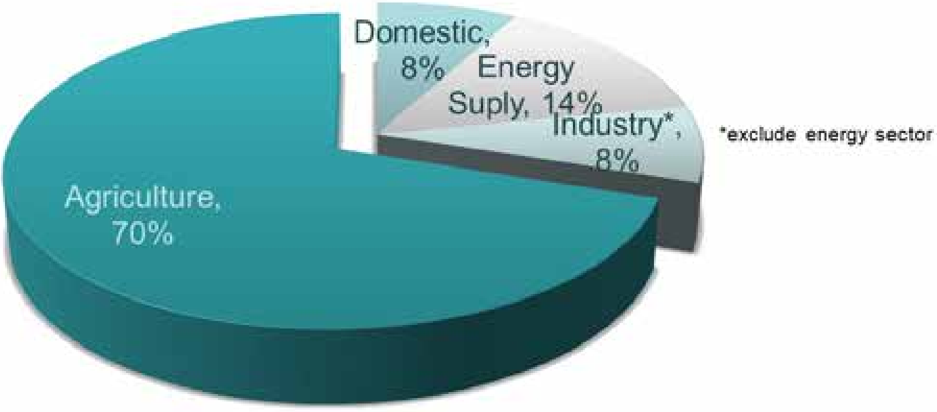
Who consume the water ?



Global use of fresh water

Reference: Coates D, et al., Water demand: What drives consumption? Managing water under uncertainty and risk – The United Nations World Water Development Report 4. Paris: UNESCO (United Nations Educational, Scientific and Cultural Organization; 2012, p.44-49

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Type of seawater desalination process

Phase-change process	Membrane process
1. Multi-stage flash (MSF)	1. Reverse Osmosis (RO)
2. Multiple effect distillation (MED)	2. Electrodialysis (ED)
3. Vapor Compression (VC)	
4. Membrane distillation (MD)	
5. Freezing	
6. Humidification/dehumidification (H/D)	
7. Solar distillers (SD)	
8. Low Temperature Thermal Distillation (LTTD)	

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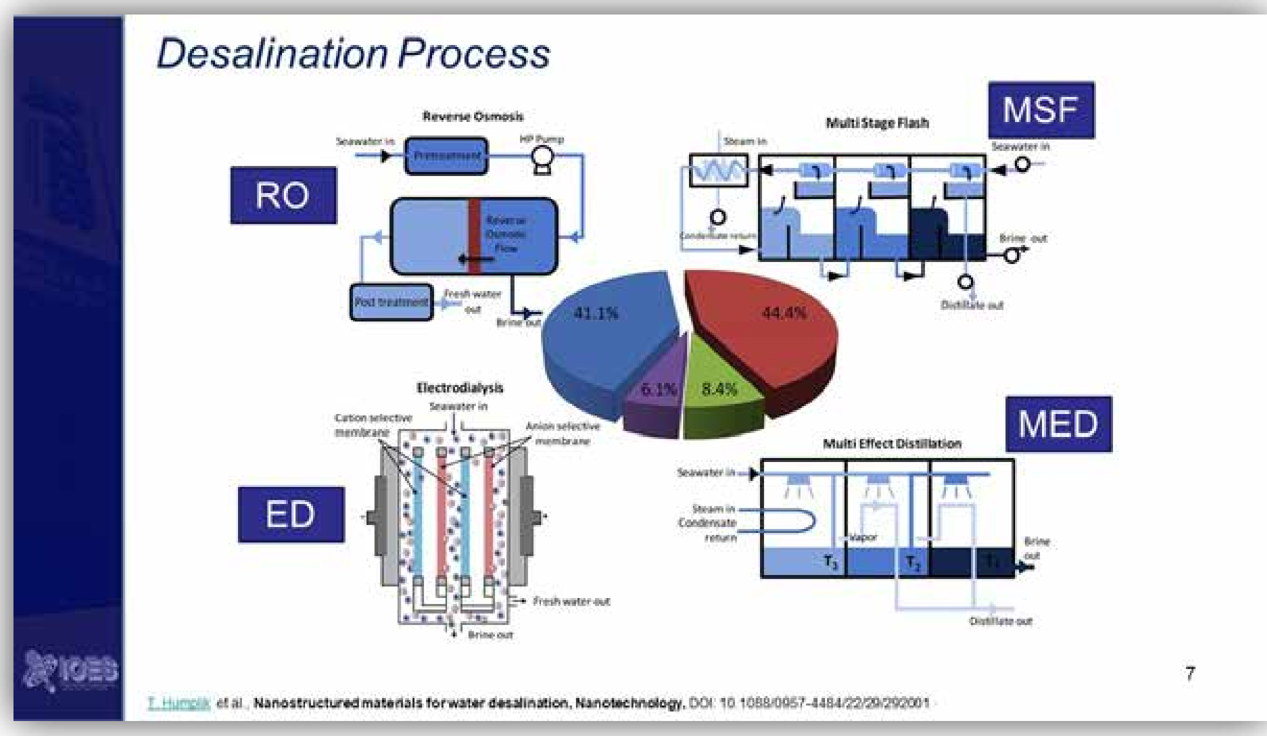
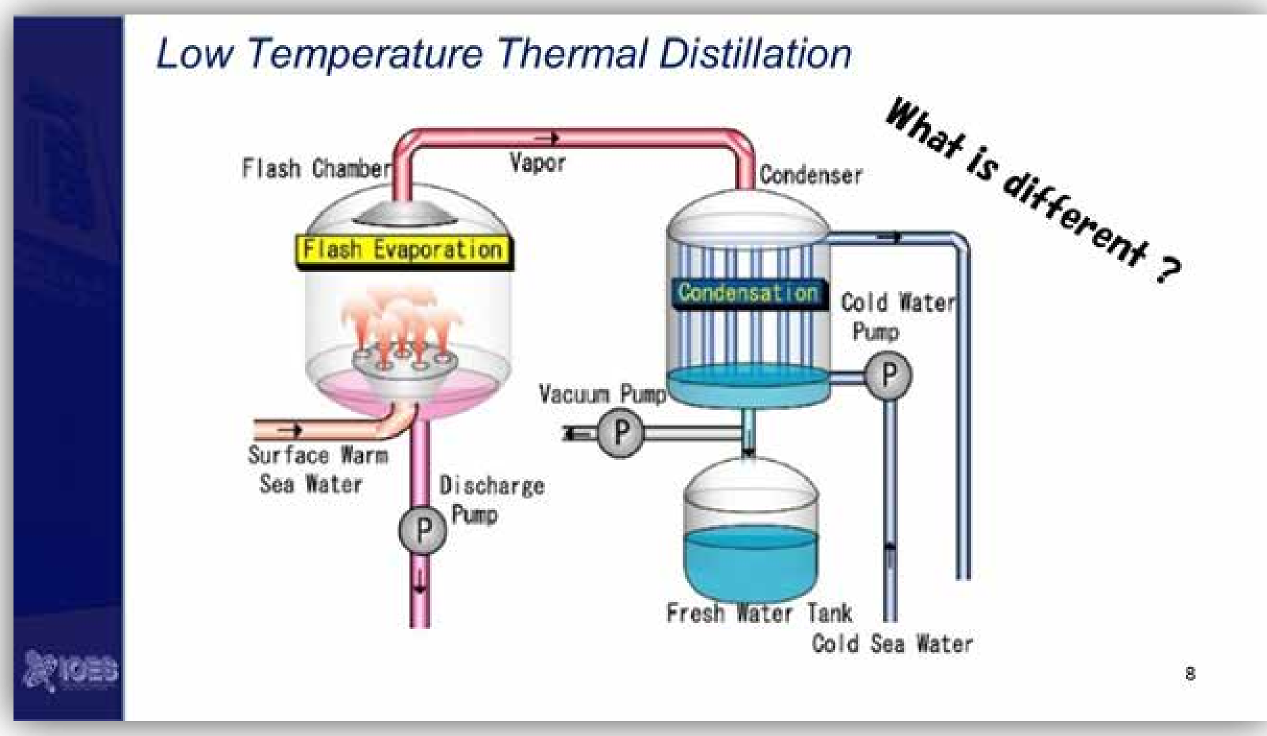
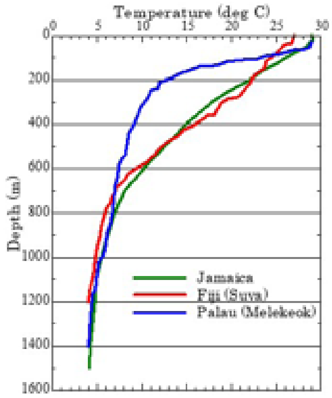
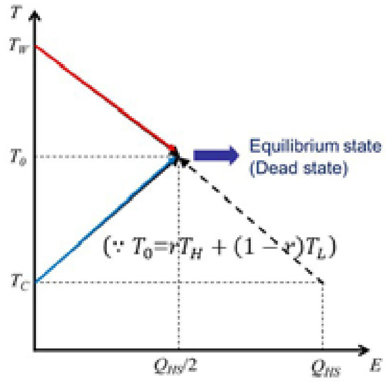

Desalination Process
Reverse Osmosis
RO
Seawater in
Pretreatment
HP Pump
Reverse Osmosis Flow
Post treatment
Fresh water out
Brine out
Multi Stage Flash
MSF
Steam in
Seawater in
Condensate return
Brine out
Distillate out
41.1%
44.4%
6.1%
8.4%
Electrodialysis
Seawater in
Cation selective membrane
Anion selective membrane
ED
Fresh water out
Brine out
Multi Effect Distillation
MED
Seawater in
Steam in
Condensate return
Vapor
Brine out
Distillate out
7
T. Humplik et al., Nanostructured materials for water desalination, Nanotechnology, DOI: 10.1088/0957-4484/22/29/292001


Low Temperature Thermal Distillation
What is different ?
Flash Chamber
Vapor
Condenser
Flash Evaporation
Condensation
Cold Water Pump
Vacuum Pump
Surface Warm Sea Water
Discharge Pump
Fresh Water Tank
Cold Sea Water
8

Thermal energy in low temperature heat





$$Q_T = \int_{T_0}^{T_H} (mC_p)_H dT + \int_{T_L}^{T_0} (mC_p)_L dT$$
$$= C_H(T_H - T_0) + C_L(T_0 - T_L)$$
$$= C_{HS}\{(1-2r)T_0 + rT_H - (1-r)T_L\}$$
$$= 2C_{HS}(T_H - T_L)r(1-r)$$

C_H: *Heat Capacity of High Temp.* [kW/K]

C_L: *Heat Capacity of Low Temp.* [kW/K]

C_{HS}: *Total HEat Capacity* ($CH + CL$)[kW/K]

$r \equiv C_H/C_{HS}$: Ratio of Available Heat Capacity

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LTTD plant in India (NIOT)

500t/day

Low Temperature Thermal Desalination Plant

Schematic Diagram of LTTD working principle

1,000t/day demonstration plant

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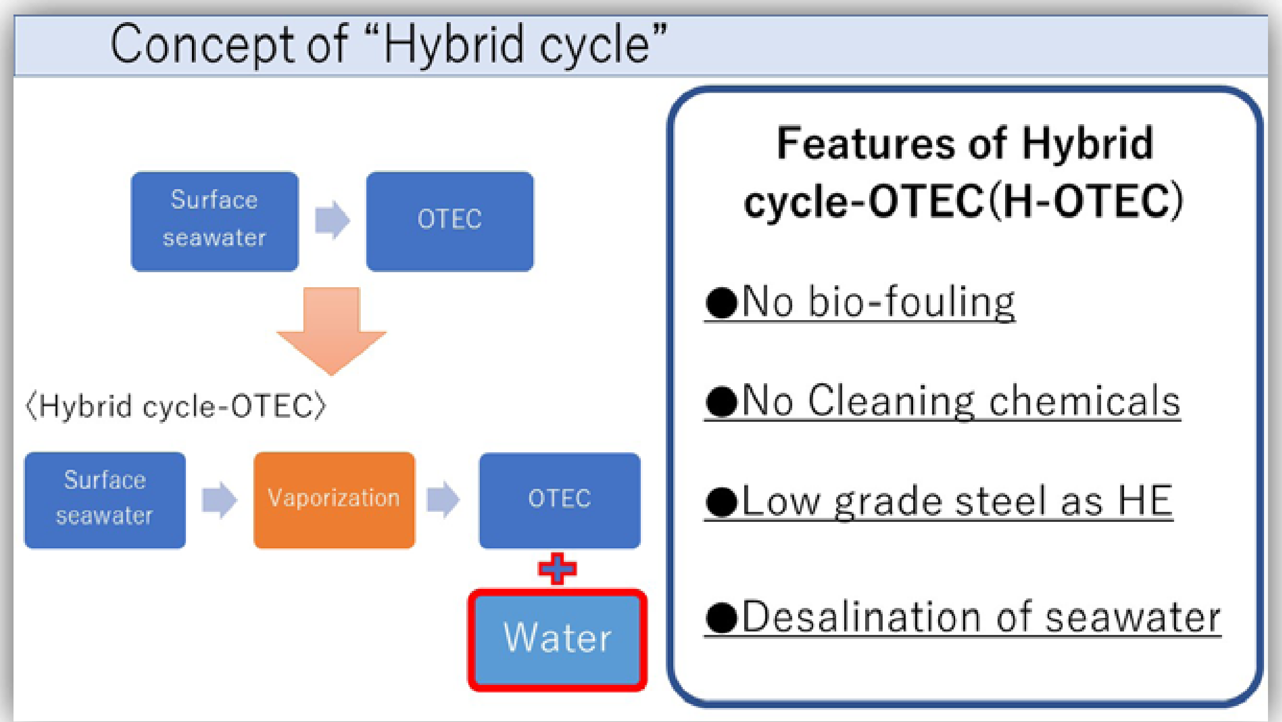
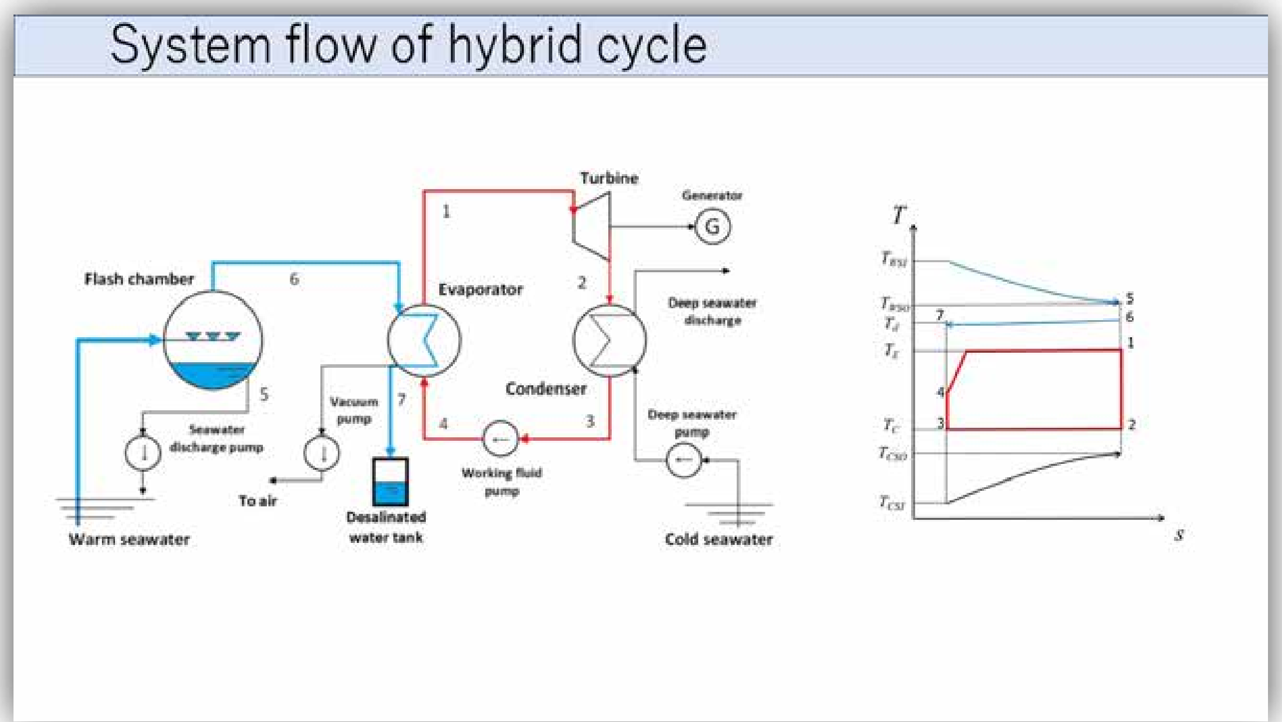

Concept of "Hybrid cycle"
Surface seawater
OTEC
〈Hybrid cycle-OTEC〉
Surface seawater
Vaporization
OTEC
Water
Features of Hybrid cycle-OTEC(H-OTEC)
●No bio-fouling
●No Cleaning chemicals
●Low grade steel as HE
●Desalination of seawater


System flow of hybrid cycle
Turbine
Generator
G
Flash chamber
Evaporator
Deep seawater discharge
Condenser
Vacuum pump
Seawater discharge pump
Deep seawater pump
Working fluid pump
To air
Desalinated water tank
Warm seawater
Cold seawater
T
s

Relational expressions (desalination)

Heat transfer rate of flash chamber

$Q_E = (mc_p)_{WS}(T_{WSI} - T_{WSO})$ m: Mass flow rate, T: Temperature

Water production amount

$m_d = Q_E / L$ L: Latent heat of vaporization

Flashed vapor temperature

$T_f = T_{WSO} - NETD - BPR$

$NETD$: Non-Equilibrium Temperature Difference

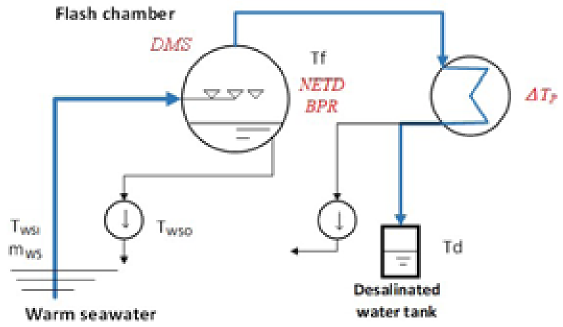
BPR : Boiling Point Rise

Desalinated water temperature

$T_d = T_f - DMS - \Delta T_P$

DMS: Loss of Demister

ΔT_P: Temperature change from Pressure loss



Relational expressions (power generation)

Heat balance equations

Evaporator

①$Q_E = m_{ws}(h_6 - h_7)$

②$Q_E = UA\Delta T_E$

③$Q_E = m_{wf}(h_1 - h_4)$

Condenser

④$Q_C = m_{wf}(h_2 - h_3)$

⑤$Q_C = UA(\Delta Tm)_C$

⑥$Q_C = m_{cs}c_p(T_{cso} - T_{csi})$

U: Overall heat transfer coefficient

Net transfer unit

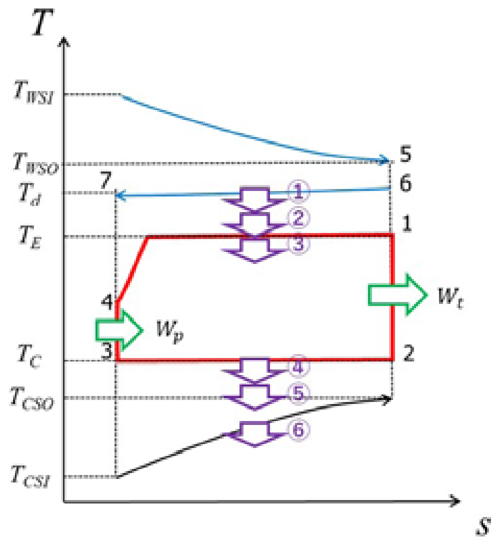
$(NTU)_E = \frac{(UA)_E}{(mc_p)_{WS}}$ $(NTU)_C = \frac{(UA)_C}{(mc_p)_{CS}}$

Turbine power

$W_t = m_{wf}(h_1 - h_2)$

Pumping power

$W_p = m_{wf}(h_4 - h_3)$



The evaluate equations

Evaluation of system performance

Thermal efficiency

$\eta_{th} = (W_T - W_P)/Q_E$

Working efficiency

$\eta_W = (W_T - W_P)/W_m$

Theoretical maximum power output

$$W_m = \frac{(mc_p)_{WS}(mc_p)_{CS}}{(mc_p)_{WS}+(mc_p)_{CS}}\left(\sqrt{T_{WSI}} - \sqrt{T_{CSI}}\right)^2$$

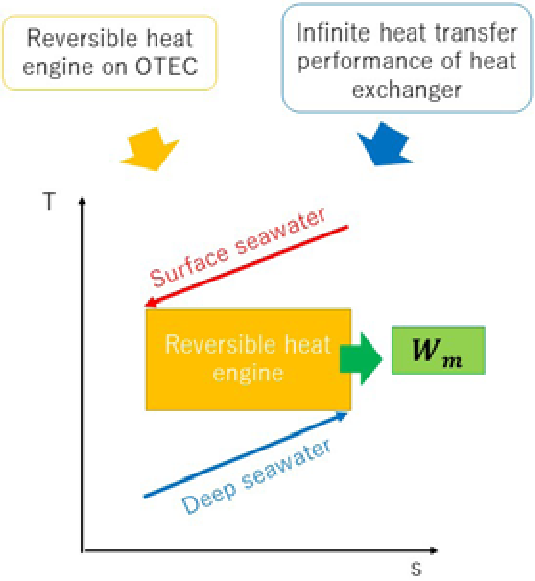
Evaluation of desalination

Recovery ratio

m_d/m_{wsi}

Specific power consumption

W_{VP}/m_d



Thermal property calculation Programs

Now days, there are many kinds of thermal property calculation software. In chemical engineering field, a lots of paid software to calculate the process and process optimization.
In IOES, we mainly use the following software, and for analysis the data, we use Fortran, Matlab and/or Excel with linking the thermal property software.

- NIST REFPROP (latest version 10.0) (Paid software)
  National Institute of Standards and Technology, US Department of Commence
  Many variety of fluids
- PROPATH (latest version 13.0) (Free for University)
  A Program Pakege for Thermophysical properties of fluids developed propath group based on Japaneses Universities and Institutions.

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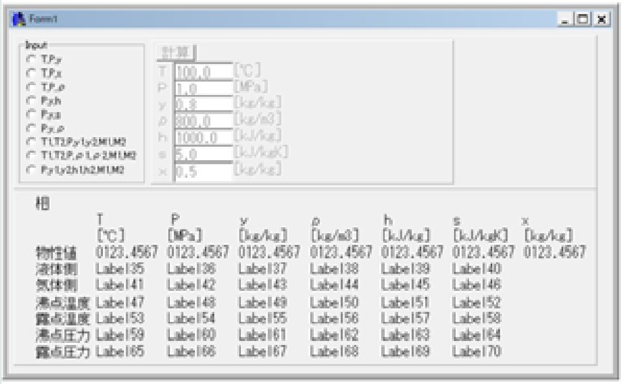
Thermal property calculation with Propath for Ammonia/water single or mixture (1 of 2)



Y=1 (pure NH_3), Y=0 (pure H_2O)

T: Temperature [°C]

P: Absolute Pressure [MPaA]

h: Specific enthalpy [kJ/kg]

s: Specific entropy [kg/kgK]

x: Vapor quality [-]

物性値 : Calculated present value
液体側 : Liquid phase value (in case the present value is tow phase)
気体側 : Vapor phase value (in case the present value is tow phase)

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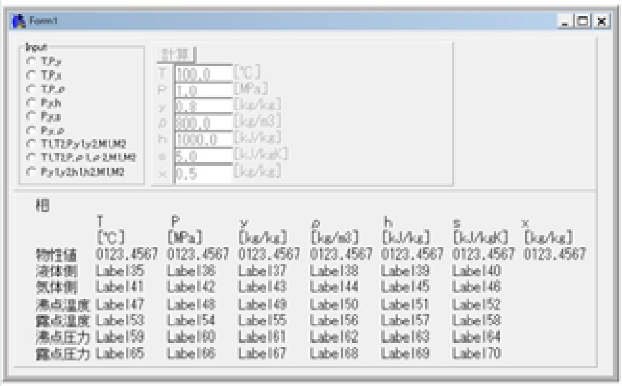
Thermal property calculation with Propath for Ammonia/water single or mixture (2 of 2)



Y=1 (pure NH_3), Y=0 (pure H_2O)

T: Temperature [°C]

P: Absolute Pressure [MPaA]

h: Specific enthalpy [kJ/kg]

s: Specific entropy [kg/kgK]

x: Vapor quality [-]

沸点温度 : Boiling point state based on input pressure
露点温度 : Dew point state based on input pressure
沸点圧力 : Boiling point state based on input temperature
露点圧力 : Dew point state based on input temperature

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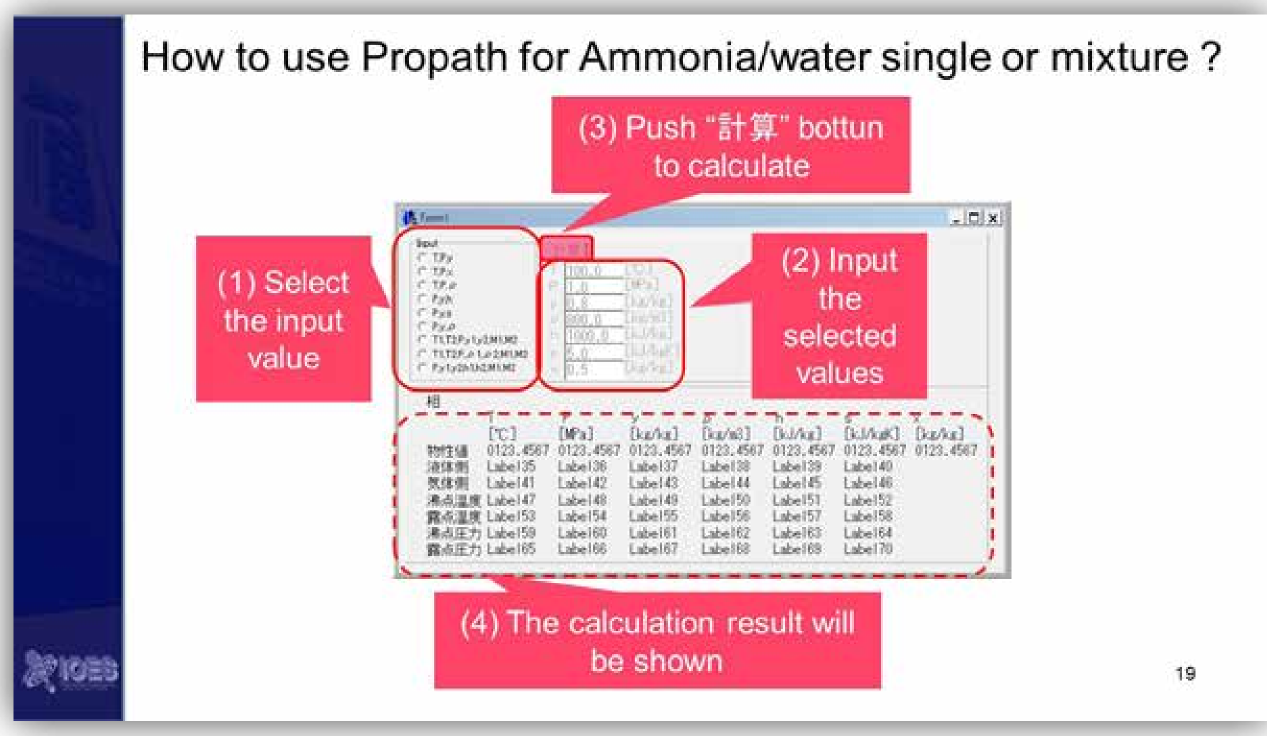

Questions ?

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SAGA UNIVERSITY

ANNEX VII PRESENTATION ON HEAT TRANSFER AND HEAT EXCHANGER FOR OTEC

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Development of Advanced Hybrid Ocean thermal Energy Conversion (OTEC) Technology for Low carbon Society and Sustainable Energy System

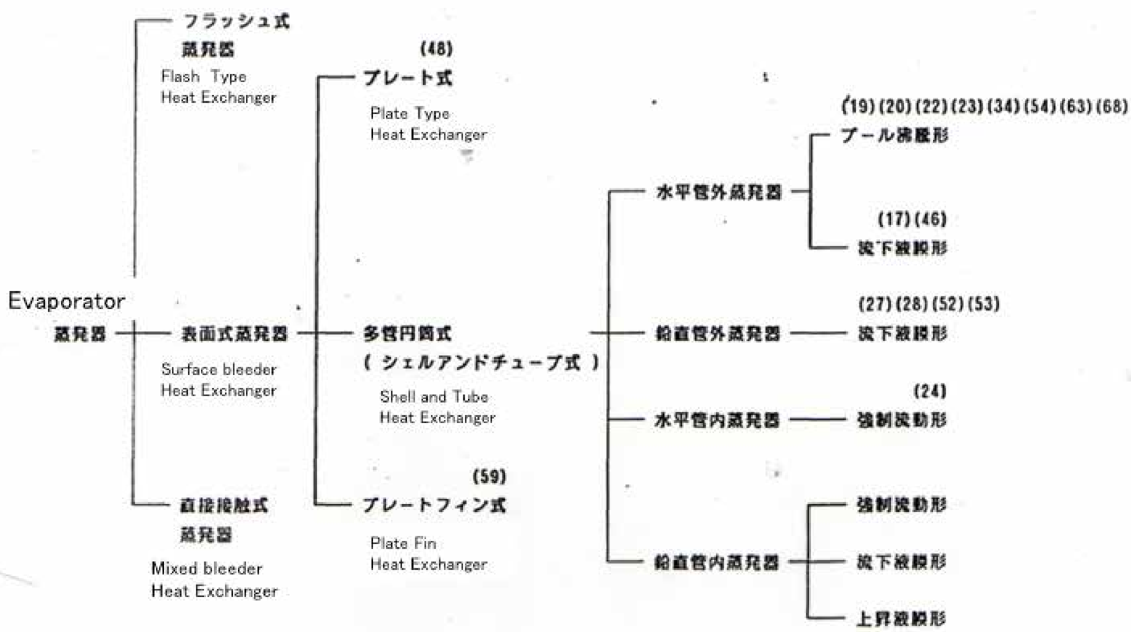
Annex VII – Design of the Plate-type Heat Exchanger

Institute of Ocean Energy, Saga University
Prof. Dr. Tsutomu Nakaoka

CONFIDENTIAL RELATED PARTIES ONLY

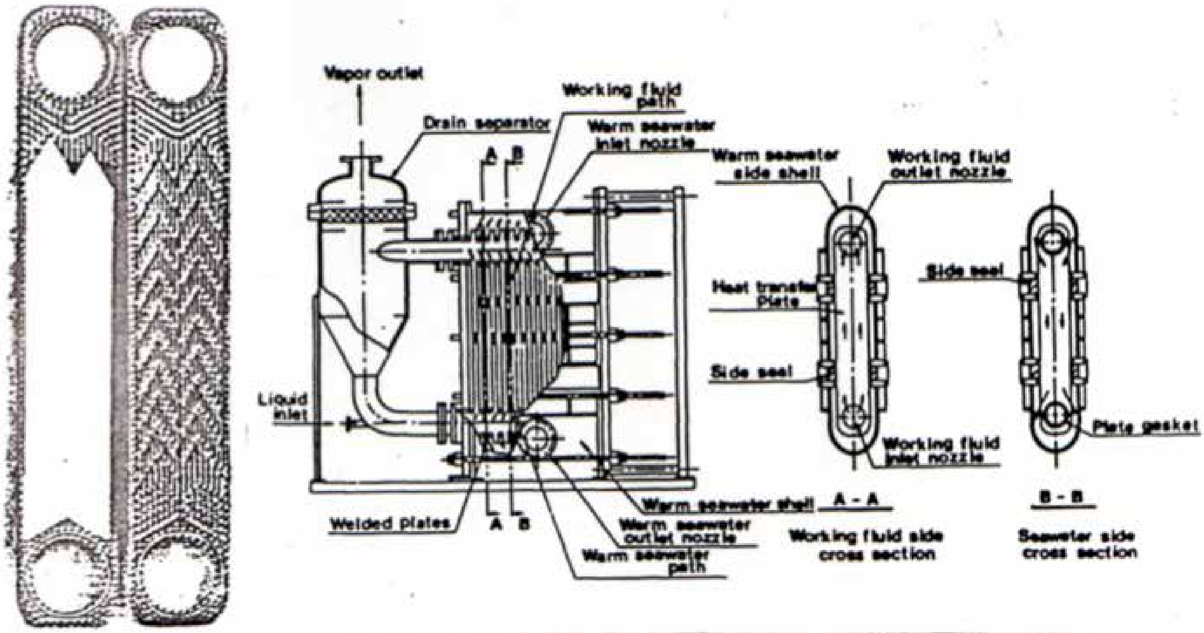
1

1. Heat Exchanger(Evaporator)



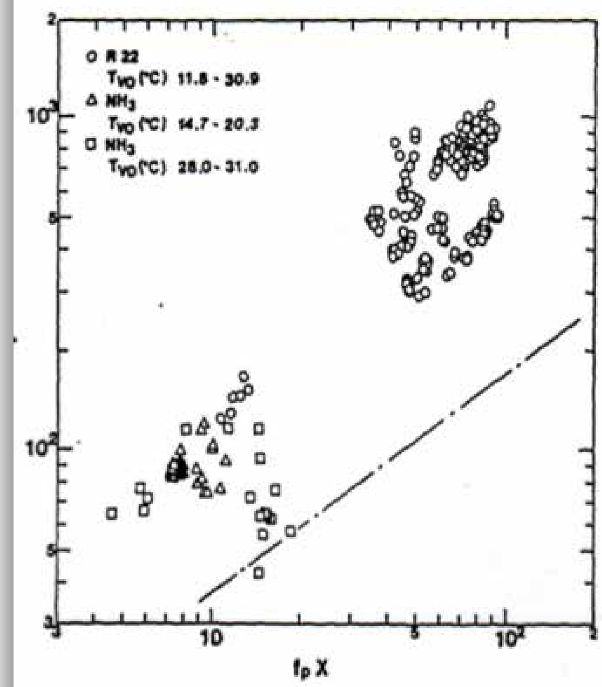
2

2. Heat Exchanger (Evaporator)

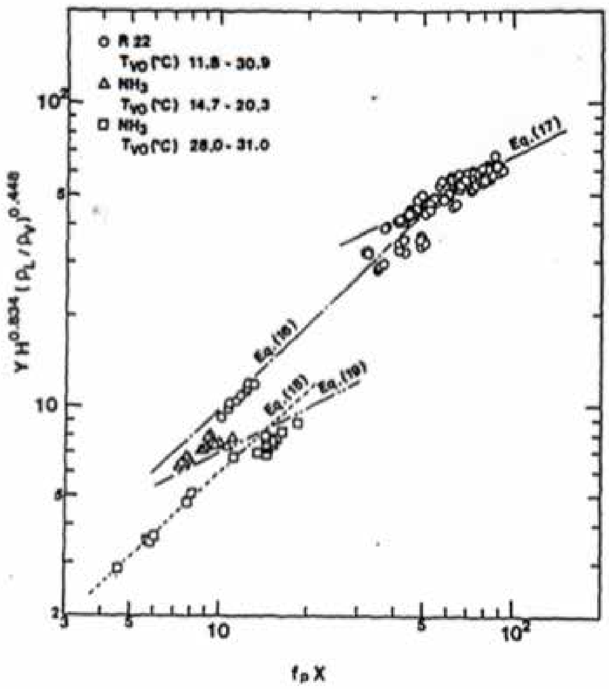


3

3. Experimental data (Plate-Type Evaporator)



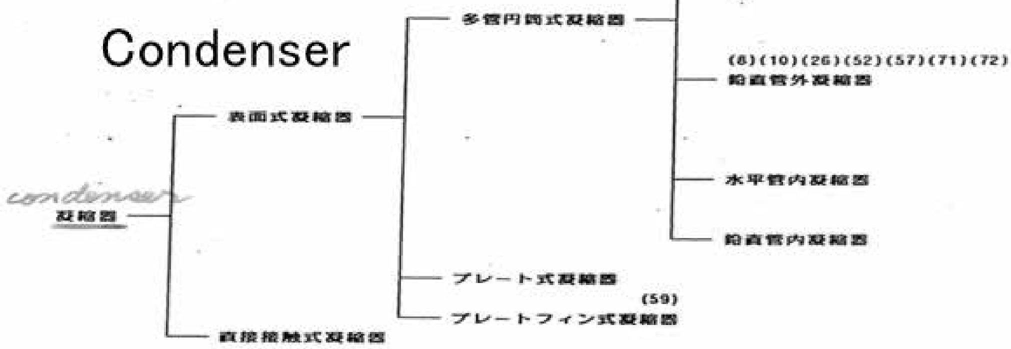
Correlation of boiling heat transfer coefficient

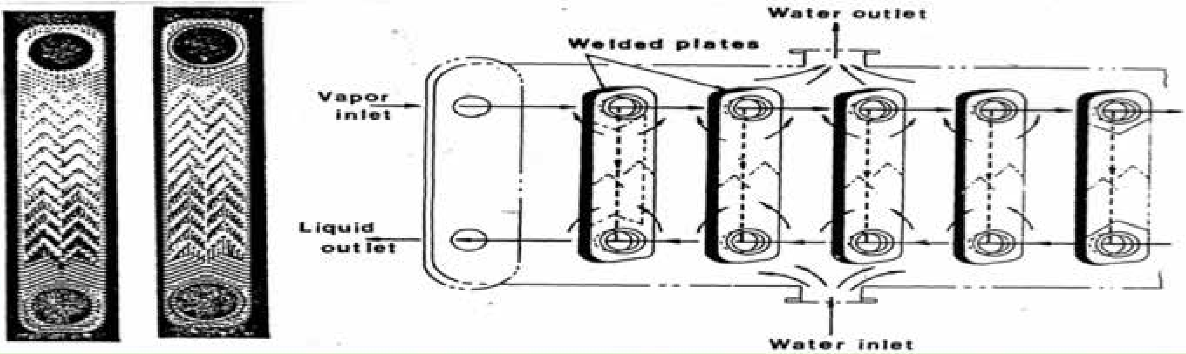


$YH^{0.834}(\rho_L/\rho_V)^{0.448} \sim f_p X$

4

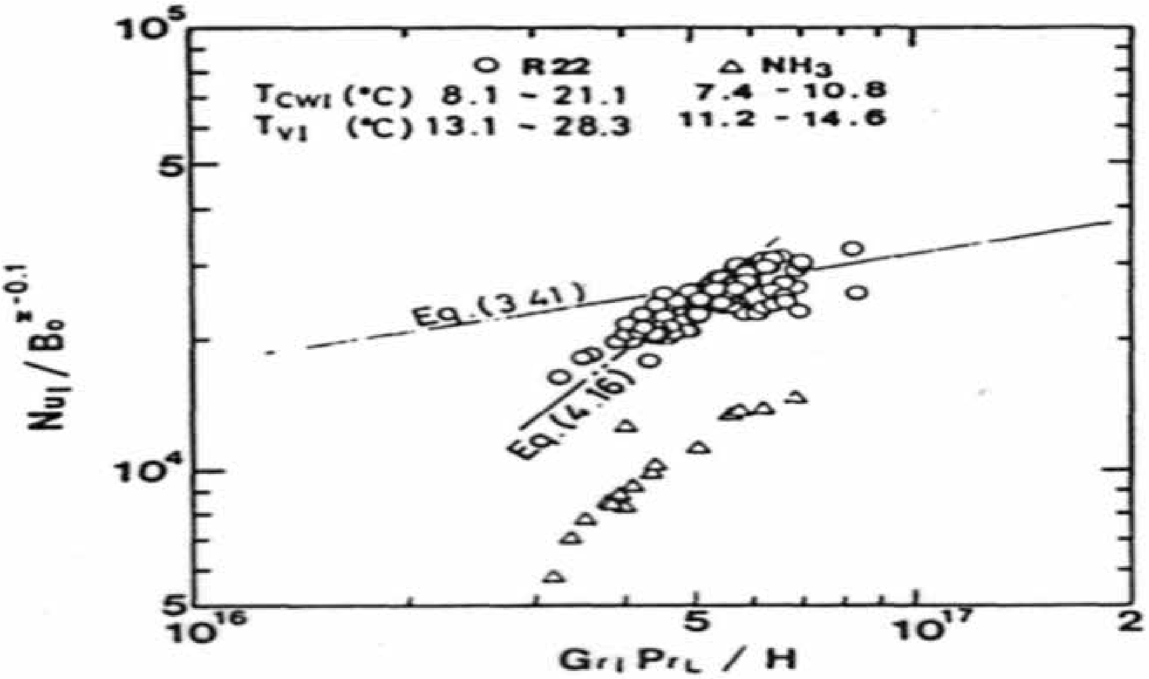
4. Heat Exchanger (Condenser)





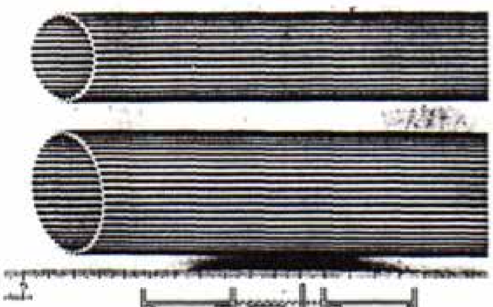
5

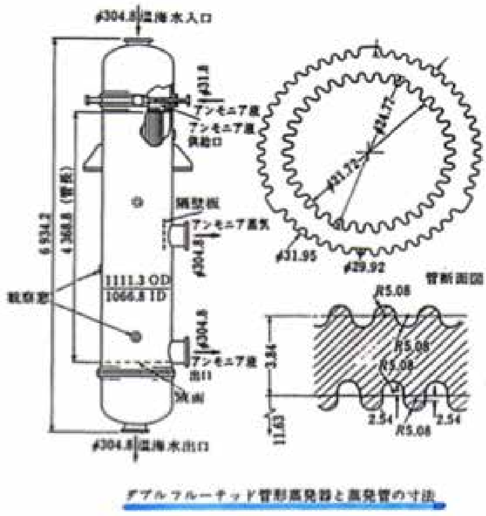
5. Experimental data (Plate-Type Condenser)

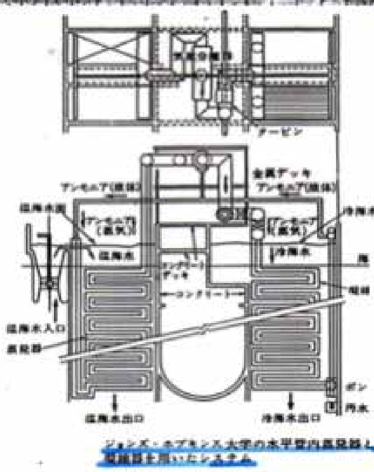


6

6. Double Fluted Tube-Type Heat Exchanger







Horizontal Tube Evaporator and Condenser (Johns Hopkins University)

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7. Design of the Plate-type Heat Exchanger

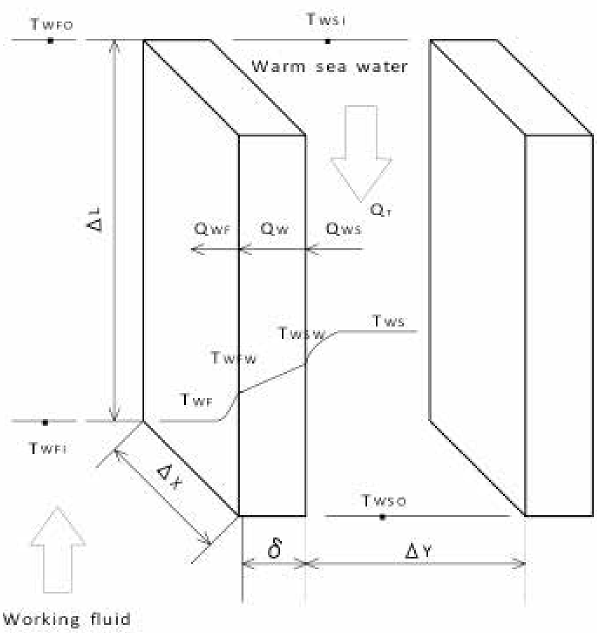

Fig. 1 Calculate model

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8. Flow chart of caluculation

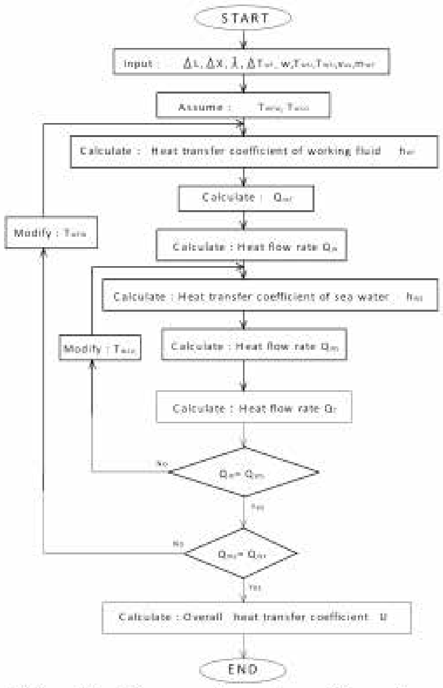

Fig. 2 Flow chart of calculation

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9. 1 Heat transfer rate

The heat transfer rate in the evaporator is calculated from following equation.

The heat transfer rate Q_T of the warm sea water side in the evaporator is calculated from following equation.

$$Q_T = m_{WS}\ c_{PWS}\ (T_{WSI} - T_{WSO}) \qquad (1)$$

Where,

m_{WS} : Flow rate of warm sea water

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c_{PWS} : Specific heat at pressure constant
T_{WSI} : Temperature of inlet warm sea water
T_{WSO} : Temperature of outlet warm sea water

The heat transfer rate Q_{WS} from warm sea water to wall is calculated from following equation.

$$Q_{WS} = h_{WS} A_E (T_{WSm} - T_{WSW}) \quad (2)$$

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Where,

h_{WS} : Heat transfer coefficient of warm sea water side
A_E : Heat transfer area of plate
T_{WSm} : Mean Temperature of warm sea water
T_{WSW} : Wall Temperature of warm sea water side

The heat transfer rate Q_W in the wall is calculated from following equation.

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$$Q_W = (\lambda/\delta)A_E\,(T_{WSW} - T_{WFW}) \qquad (3)$$

Where,

- λ : Heat conductivity of plate
- δ : Thickness of plate
- T_{WSW} : Wall Temperature of warm sea water side
- T_{WFW} : Wall Temperature of working fluid side

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The heat transfer rate Q_{WF} from wall to working fluid is calculated from following equation.

$$Q_{WF} = h_{WF}\ A_E\ (T_{WFW} - T_{WFm}) \qquad (4)$$

Where,

- h_{WF} : Heat transfer coefficient of working fluid side
- A_E : Heat transfer area of plate
- T_{WFW} : Wall Temperature of working fluid side

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T_{WFm} : Mean Temperature of working fluid

9.2 Heat transfer coefficient of the warm sea water

Uehara et. al. (1986) proposed an empirical equation of the heat transfer coefficient of the warm sea water.

The heat transfer coefficient of the warm sea water h_{ws} in Eq. (2) is calculated from the following equation.

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$$Nu_{WS} = 0.058 Re_{WS}^{0.8} Pr_{WS}^{1/3} \quad (5)$$

Where,

$$Nu_{WS} = (h_{WS}\, Deq_{WS}) / \lambda_{WS} \quad (6)$$

$$Re_{WS} = (v_{WS}\, Deq_{WS}) / \nu_{WS} \quad (7)$$

$$Pr_{WS} = (c_{Pws}\, \mu_{WS}) / \lambda_{WS} \quad (8)$$

9.3 Heat transfer coefficient of the working fluid

Kushibe et. al.(2006) proposed an empirical equation of the heat transfer coefficient of the working fluid.

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The heat transfer coefficient of the working fluid h_{wF} in Eq. (4) is calculated from the following equation.

$$h_{LV}/h_{WF} = 1.5 \ (1/\chi_{tt})^{0.85} \qquad (9)$$

Where,

$$h_{LV} = C \ (\lambda_L/Deq)\{G_{WF}(1-\chi_0) \ Deq/\mu_L\}^{0.8} Pr_L^{1/3} \qquad (10)$$

$$\chi_{tt} = \{(1-\chi_0)/\chi_0\}^{0.8} (\rho_V/\rho_L)^{0.5} (\mu_L/\mu_V)^{0.1} \qquad (11)$$

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Where,

C is constant coefficient (C=0.058)

9.4 Overall heat transfer coefficient of the warm sea water

If the heat transfer rate in equation (1), (2), (3), (4), the heat transfer coefficient of warm sea water side and the heat transfer in working fluid side is found,

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Overall heat transfer coefficient U in the evaporator can be calculated from following equation.

$$1/U = (1/h_{WS} + \lambda/\delta + 1/h_{WF}) \qquad (12)$$

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Overall heat transfer coefficient U_E in the evaporator can be calculated from following equation.

$$U_E = Q_E / (A_E \, \Delta T_{mE}) \qquad (13)$$

Where,

Q_E : Heat flow rate

A_E : Heat transfer area

ΔT_{mE} : Logarithmic mean temperature difference

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Logarithmic Mean Temperature Difference ΔT_{mE}

$$\Delta T_{mE} = (T_{WSI} - T_{WFO}) - (T_{WSO} - T_{WFI}) / (\ln (T_{WSI} - T_{WFO}) / (T_{WSO} - T_{WFI})) \quad (14)$$

Where,

T_{WSI} : Inlet temperature of sea water
T_{WSO} : Outlet temperature of sea water
T_{WFI} : Inlet temperature of working fluid
T_{WFO} : Outlet temperature of working fluid

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2.1 Overall Heat Transfer Coefficient

Heat Conduction } Overall Heat Transfer Coefficient
Heat Convection

Hight temperature gas → Surface wall I : Heat Convection

$$q_{g-I} = \alpha_g (T_g - T_1) \qquad (2.1)$$

Surface wall I → Surface wall II : Heat Conduction

$$q_{I-II} = -\lambda \left(\frac{T_2 - T_1}{L}\right) \qquad (2.2)$$

Appendix

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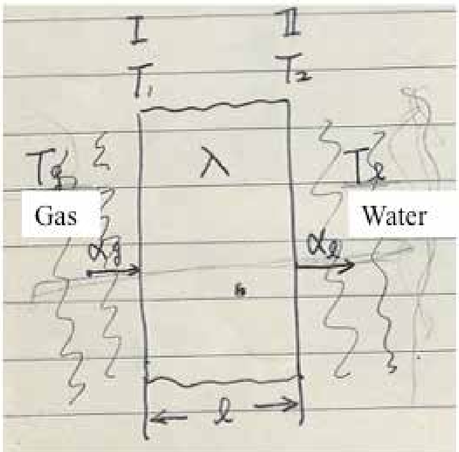

Surface wall II→ Matter of Low temperature : Heat Convection

$$q_{II-1} = \alpha_1 (T_2 - T_1) \qquad (2.3)$$

At Steady

$$q_{g-I} = q_{I-II} = q_{II-1} = q \qquad (2.4)$$

Rewrite

$$T_g - T_1 = \frac{q_{g-I}}{\alpha_g} \qquad (2.5)$$

$$T_1 - T_2 = \frac{q_{I\_II}}{\lambda} L \qquad (2.6)$$

$$T_2 - T_1 = \frac{q_{II-I}}{\alpha_1} \qquad (2.7)$$

$$T_g - T_1 = q \left(\frac{1}{\alpha_g} + \frac{L}{\lambda} + \frac{1}{\alpha_1} \right) \qquad (2.8)$$

$$\therefore \quad q = \frac{T_g - T_l}{\frac{1}{\alpha_g} + \frac{L}{\lambda} + \frac{1}{\alpha_l}} \qquad (2.9)$$

Local thermal Resistance R ;

$$R = \frac{1}{\alpha_g} + \frac{L}{\lambda} + \frac{1}{\alpha_l} \qquad (2.10)$$

$$q = \frac{\Delta T}{R} \quad = K\Delta T \qquad (2.11)$$

$$\Delta T = T_g - T_l \qquad (2.12)$$

$$K = \frac{1}{R} \qquad (2.13)$$

K : Overall Heat Transfer Coefficient

Abbreviation

DSW	Deep Seawater
GOSEA	Global Ocean reSource and Energy Association Institute
H-OTEC	Hybrid Ocean Thermal Energy Conversion
I-AQUAS	International Institute of Aquaculture and Aquatic Sciences
IOES	Institute of Ocean Energy, Saga University (IOES)
JFY	Japanese Financial Year (April -March)
JICA	Japan International Cooperation Agency
JST	Japan Science and Technology Agency
OTEC	Ocean Thermal Energy Conversion
R&D	Research & Development
SATREPS	Science and Technology Research Partnership for Sustainable Development
SDGs	Sustainable Development Goals (United Nations)
SU	Saga Univerity
UKM	University Kebangsaan Malaysia
UM	University of Malaya
UMT	University Malaysia Terengganu
UTM	University Teknologi Malaysia
UPM	University Putra Malaysia

MEMORY PHOTO COLLAGE


深層水取水管


Surface Water
W.F. Pump
海水の流れ
深層海水
・流量：最大 540t/h
既存取水設備と共用
・取水深度：612m
・水温：年間平均 9℃
（ほぼ一定）
表層海水


沖縄県
Ocean Thermal
Energy Conversion


Xenesys
OTEC R&D Center


IOES
SATREPS PROJECT
Ocean Thermal Energy Conversion
UTM
OTEC
SATREPS
Development of Advanced Hybrid Ocean Thermal Energy Conversion (OTEC) Technology for Low Carbon Society and Sustainable Energy System : First Experimental OTEC Plant of Malaysia


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Ocean Thermal Energy Conversion
OTEC
SATREPS


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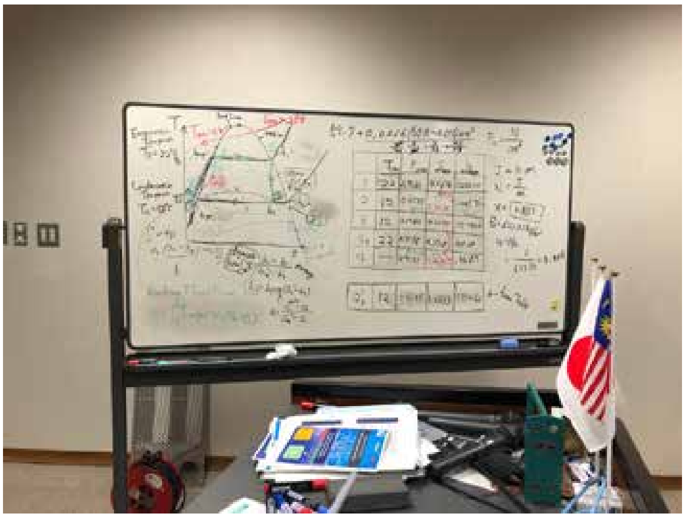


SATREPS

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