STUDIES ON PERFORMANCE OF WORKING FLUIDS ON THE OCEAN THERMAL ENERGY CONVERSION PLANT

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Abstract – *Ocean thermal energy conversion (OTEC) is reliable, inexhaustible source of renewable energy harnessed from ocean surface. The OTEC is a low temperature power generating cycle, consequently OTEC systems have lower thermal efficiency about 3% to 5%.The efficiency of any power generating cycle primarily rely on operating fluid of cycle. The objective of present study is to select an optimal working fluid for OTEC's thermodynamic cycle. The refrigerants are used as operating fluid for a closed cycle OTEC (CC-OTEC). The Ammonia, Aqua-ammonia (90:10) and R32 are the selected fluids for study. The equatorial latitude is most suitable region for a required temperature gradient of 15°C to 20°C along depth of sea surface which is as per sea surface temperature (SST) record. Analytical calculations are performed for a CC-OTEC Rankine cycle for temperature gradient of 26°C to 8°C. The results indicate that maximum thermal efficiency and net work done is shown by Aqua-ammonia and lowest by R32. In deployment of plant, major concern is the overall cost of plant which mainly constitutes the cost of working fluid and mechanical components. The results certainly exhibits that ammonia plant operates at 21700 USD/Net Power (kW) which is costliest as compared to that of R32 and Aqua-ammonia. The fluid R32 scale backs cost associated with piping and low turbine size which reduces overall infrastructure cost. The use of ammonia based fluid ads up more maintenance cost. The environmental parameters are the key criteria for selection of any refrigerant. All the selected fluids have less flammability than other refrigerants available. The ozone depletion potential (ODP) all the three selected fluids is zero. It is observed that the fluid ammonia and aqua-ammonia possess high toxicity as compared to R32. Despite of having low thermal performance of R32, it can be used against ammonia based refrigerants for safe plant operation. The fluid aqua-ammonia gives overall best thermal and economic performance, therefore aqua-ammonia has a potential to replace all traditional working fluids used for OTEC plant, as it enhances plant performance and ensures cleaner, safer and eco-friendly plant operation.*

***Key Words*: OTEC, Working fluids, Temperature, Refrigerants, Renewable energy, Efficiency, Environmental parameters**

1. INTRODUCTION

The Ocean thermal energy conversion (OTEC) is a revolutionary technology consisting of power generating thermodynamic cycles working at low temperature. It is used to harvest energy from ocean surface. The OTEC works as zero carbon emission plants. Pumps are solely the most power absorbing devices which can be driven through by-pass power generated by plant, hence a fuel less operation. OTEC Is a Continues power source providing (24/7) power and has cleaner, Greener & Environment sustainable operation. Operating cost of an OTEC plant is negligible. Heat Exchangers are the single most expensive component in a commercial offshore OTEC plant [3] .OTEC is label as "green and free energy" technology. The first working models of this concept was engineered and designed by French inventor Georges Claude [1]. OTEC takes advantage of equatorial belt of earth having suitable sea surface temperature (SST) for operation of plant. The potential sites for the deployment of plant are Hawaii, coastal region of India, Sri Lanka, Thailand, and Japan. First commercial OTEC plant was established by Makai ocean engineering in the year 2015. This plant enabled successfully to satisfy the power demand of hundreds of Hawaii houses. 180,000 MW capacity OTEC plat is setup by govt. of India in the year 1998.Additionally India designed and built a 1MW floating OTEC pilot plant 35km off coast off the coast of Tiruchendur, Tamil Nadu. Similar projects are planned for Andhra Pradesh [2].

OTEC plants are deployed on water bodies, certainly main impacts with this technology are on ocean bodies and marine life. Pumping operation causes transfer of local plants & nutrients to top surface inflicting increase of nutrient-rich deep ocean water on the surface that ends up in proliferation of harmful algal blooms (HAB) [4]. Discharge of cold water on top surface causes decrease temperature gradient which affects aquatic biota. The problems like noise, pollutant concentration, collision risk for fish and birds, plume discharge, EMF from transmission lines may result in decline of native marine population & absence of pelagic fish species. OTEC's operation will unavoidably affect pelagic fish[5].In 21st Century Due to limitation of fossil fuels and ever increasing cost of fuels Society needs to focus on Renewable Energy resources ,This sources are less efficient but More sustainable. Subsequently the thermal efficiency of the cycle is theoretically small and generally in the range of 3% to 5%. Therefore, improvement of the system performance of the OTEC system is of enormous importance[6].The major factor affecting performance of plant are working fluid for cycle & design of heat exchanger(hx). Knowledge of cycle fluid is important, certainly effects of working fluid on environment, risk associated with it, maintenance , cost of operation , performance are factors taken into account. Purpose of present study is to find out an appropriate working fluid having optimum performance characteristics.

OTEC has capacity about 1MW to 10MW. A 1MW Power is enough to illuminate around 600 medium sized homes. Subsequently many Island & Costal communities are trying forward to install OTEC facility in regions. OTEC Projects plays an important role in fulfilling the socio-political aspects such as tourism, nature conservation, can provide employment, etc. thus OTEC project are helpful to boost the overall Society Welfare. Focusing on positive aspects of OTEC and implementation of this state of art green technology will be a step forward in field of renewable energy .This technology has potential to address need of society to shift for new renewable source of energy like OTEC.

2. THERMODYNAMIC CYCLES OF OTEC

2.1 Claude's cycle (OC-OTEC)

As per Claude's concern regarding the cost and potential and bio-fouling of closed cycle heat exchangers led him to propose a design in which steam is generated directly using warm sea water [7] .Working flow of OC-OTEC:- 1) warm surface water is flash evaporated to form dry steam 2) Dry steam is circulated to turbine to produce work 3)Expanded steam is extracted and brought with direct contact with cold deep sea water pumped from depth of water bodies ,where steam is condensed by film-wise condensation to supply desalinated water. This desalinated water may be further used for drinking in addition as agricultural functions, for coastal regions. For this purpose larger diameter pipes offshore techniques used to deploy large segmented pipes made of steel, concrete or fiberglass reinforced plastic (FRP) are applicable[8] . OC-OTEC possesses use of flash evaporator certainly, OC-OTEC is more complicated than CC-OTEC.

2.2 Anderson's cycle (CC-OTEC)

The Anderson's & D'Arsonval's idea regarding the closed cycle was to use a working fluid in a closed loop that result in increase in efficiency as compared to OC-OTEC. The refrigerants were identified as a suitable fluid for this cycle.CC-OTEC uses integration of components such as heat exchangers, pumps, turbine, condensers, rectifier strip, etc. Use of superheaters is not recommended. Flow path of CC-OTEC is as: - 1) Phase change (evaporation) of refrigerant in heat exchanger with warm surface water as hot fluid. 2) Dry steam drives turbine to produce work output. 3)Expanded steam is by-passed to condenser where wet steam of refrigerant come in contact with cold deep sea water and is then condensed. 4) Pumping of condensed refrigerant again back in loop to heat exchanger, and thus the process continues. The tube size and turbine diameter are much smaller than in the open cycle [9].The overall infrastructure cost of CC-OTEC is less than OC-OTEC plant.

3. SIGNIFICANCE OF REFRIGERANT

The refrigerants are fluids usually used in heat pumps for refrigerators as they possess gaseous state at STP. There are about 40 refrigerant compounds and 200 absorbent compounds available [10].For current study refrigerants acts as a fluid for heat engine. . The refrigerants are classified into two categories such as 1) Pure fluid, which is a single component fluid e.g. R134a, ammonia 2) Pseudo-pure, which is a mixture of two or more fluids e.g. Aqua-ammonia, R410a, R404a etc. The earlier mechanical refrigeration system was consisted of sulphur dioxides, CFCs, etc. As per environmental regulations under Kyoto protocol in the year 1997 banned to use these refrigerants. The ammonia was brought into heavy industrial use. The Ammonia is a cost-efficient and efficient alternative to CFCs and HCFCs. It is safe for the environment [11].The recent development in pseudo fluids and new fluids are safe and eco-friendly due to low Global Warming Potential. There are fluids such as R32, R134a, R410a and R404a are developed. The use of non-azeotropic mixtures like ammonia and water in homogenous mixture are working fluid used in power generation system, which is proposed by Kalina [12].

4. MATERIALS AND METHODOLOGY

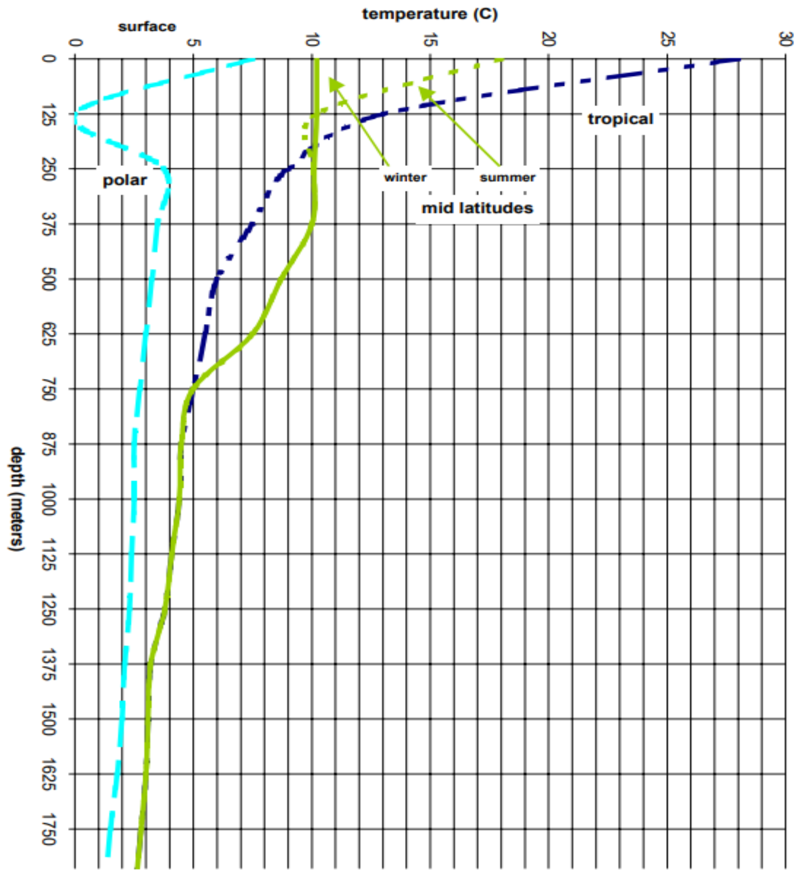

Fig-a: Vertical thermal structure of the ocean (depth vs temperature)

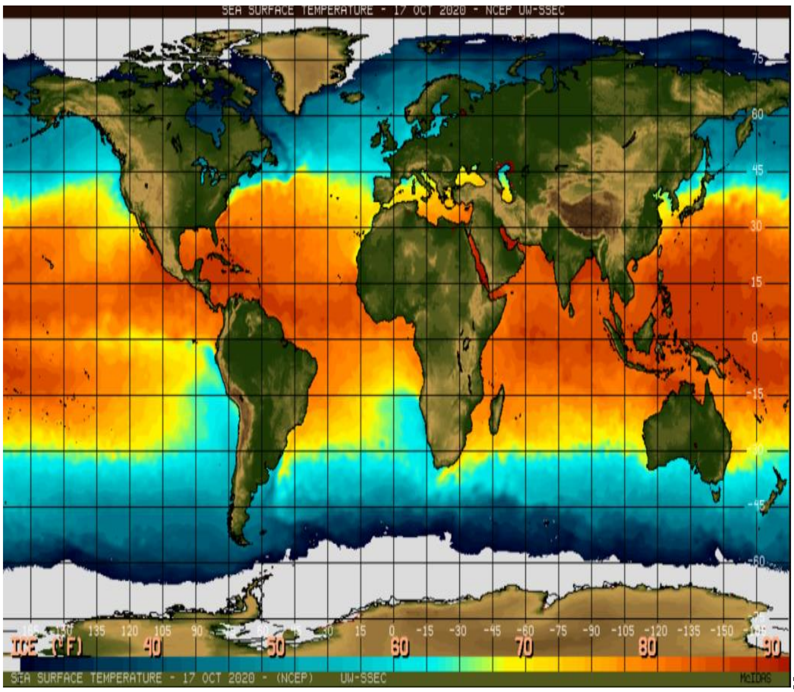

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Fig-b Sea Surface Temperature Variation (courtesy -*The NOAA National Centre for Environmental Prediction (NCEP) optimum interpolation (OI) sea surface temperature (SST))*

The desired differential temperature required to run the OTEC system is about 15°C-20°C [9]. Consequently fig.b conveys that potential site required for suitable SST (sea surface temperature) is region on equatorial latitude. From fig.b SST nearby Indian peninsula is averagely 26°C.The fig. a shows thermocline nature of SST along depth of water bodies. Thus, net difference between highest and lowest temperature for cycle should be maintain between 15°C-20°C .Therefore, the lowest temperature suitable for OTEC plant according to depth of ocean 500m to 650m from fig.a is selected as 8°C. Consequently OTEC cycle under current study will work between boundary temperatures of 26°C to 8°C.

4.1 Selection of working fluid:

The fluid selection process plays an important part in working of cycle. Selected working fluid decides the overall performance of thermodynamic cycle. The three potential working fluids were selected to study the performance on OTEC. The fluids selected were Ammonia, Aqua-ammonia (90:10) and R32. The selection of fluids were made on the basis of properties such as boiling point, latent heat, specific heat, thermal conductivity, flash point, boiling temperature, chemical stability, and toxicity.

(A) Ammonia

Ammonia refrigerant is a popular working fluid in heavy industrial HVAC&R applications. Boiling point of ammonia is -33.34°C. Ammonia is an alkaline & colourless compound. Ammonia is not a contributor to ozone depletion or global warming [14]. 99.8% pure ammonia is used as for refrigerant purpose, below threshold concentration of 5ppm. Ammonia is an easily accessible, inexpensive compound. The latent heat content of ammonia is high at room temperatures. The cuprous alloys cannot be used with ammonia because of stress corrosion cracking problems [16].The avg. lifetime of ammonia based plants is about 40 years.

(B) Aqua-ammonia (90:10)

As per concentration regulation for use of ammonia in household purposes homogeneous mixture on water and ammonia is used. Because of addition of water in ammonia toxicity of compound is reduced. Performance of aqua –ammonia is better than that of Fluoro-Carbon refrigerant [10].The mixture of ammonia and water is volatile thus rectifier is used to strip water which is evaporated with ammonia.

(C) R32

R32 is considered as a next generation refrigerant which efficiently carries heat and lowers the environmental impacts. Presently R32 is wide used as compatible fluid for household requirement. It is selected for study due to its unique properties. The boiling point of R32 is -51.7°C. It shows lower density and viscosity. It possesses higher volumetric cooling effect capacity and allowing reducing the pipe size. It increases the efficiency of the system[16]. As a single component gas R32 is easy to produced and maintain.

Above mentioned refrigerants satisfies all the conditions which a refrigerant based heat engine especially for OTEC cycle should possess. The refrigerants show many engrossing & contrasting properties over other refrigerants available. Thus, Ammonia, Aqua-ammonia & R32 are selected as working fluid under study.

Refrigerant	Temperature (°C)	Saturation pressure (kPa)	Liquid enthalpy (kJ/kg)	Vapour enthalpy (kJ/kg)	Liquid entropy (kJ/kgK)	Vapour entropy (kJ/kgK)	Liquid density (kg/m^3)	Vapour density (kg/m^3)
Ammonia	8.00	573.70	380.36	1613.4	1.605	5.990	627.46	4.5545
	26.00	1034.5	465.62	1627.2	1.8963	5.7792	601.26	8.0443
Water + Ammonia	8.00	517.17	267.60	1745.2	1.411	8.268	670.40	0.0677
	26.00	930.34	353.06	1781.0	1.704	7.852	646.45	0.1943
R32	8.00	1042.6	214.15	516.47	1.050	2.125	1027.0	28.426
	26.00	1735.3	247.53	516.39	1.162	2.0616	956.82	48.745

Table-1: Thermodynamic and thermo-physical properties of selected fluids

Table 1 contains thermodynamic, thermo physical properties of selected fluids. The values are extracted from data base in NIST RefProp 9 .The data is used for analytical calculations for thermodynamic performance of OTEC closed cycle. Data shows values of enthalpy, entropy, density under vapour and liquid states within the specified boundary temperature of 26°C to 8°C.

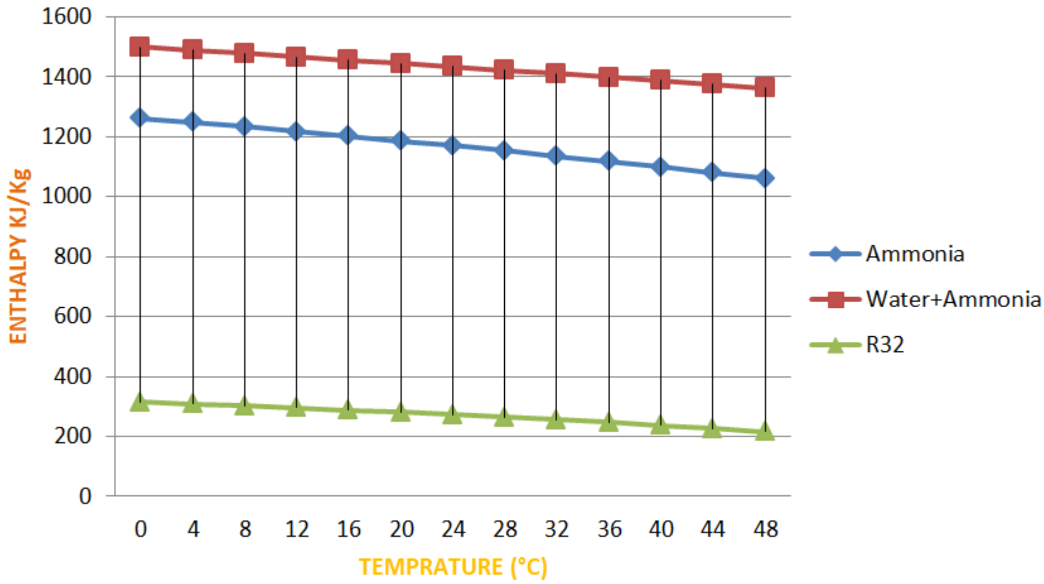

Chart-1: Enthalpy-Temperature diagram

Simulation chart 1 is based upon thermodynamic properties as per table 1. It shows variation of enthalpy (internal energy) along temperature range. It clearly exhibits that aqua-ammonia has high enthalpy compared to other two refrigerants. Selected working fluids have appreciable content of internal energy to produce required work output.

Required boundary conditions and thermo physical properties of selected working fluid are obtained. The Rankine cycle thus obtained are analysed by analytical calculations, to obtain values of thermal efficiency, pump work, net work done. The results obtained are compared amongst selected working fluids to study their thermal performances. The three fluids are examined based upon their techno-economic performance. In any refrigerant selection, their environmental consequences plays a very important role , certainly the three fluids will be once more studied in line with their environmental performances like GWP(global warming potential),ODP(ozone depletion potential) based upon ASHRAE criterion therefore, according to objective of this paper, the suitable fluid based upon this mentioned parameter is determined.

5. CALCULATION

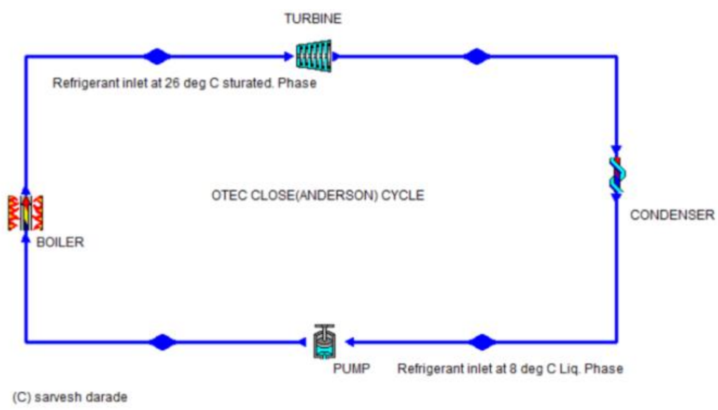

Fig-c: Schematic cycle of CC-OTEC (*with main components*)

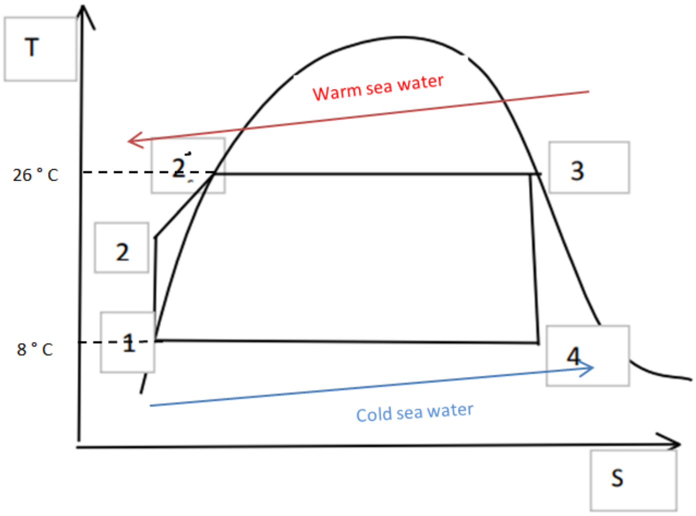

Fig-d: Temperature-Entropy curve for CC-OTEC

Fig.c shows plant cycle with block diagrams and flow path of main components.

The (CC-OTEC) Cycle is plot in the T-S diagram of Anderson cycle in fig.d

Following assumptions were made throughout calculation

1) Heat loss and pressure drop in pipes and components are neglected.
2) Pump and turbine behaves as isentropically.

The highest and lowest temperature of cycle is 26°C & 8°C Respectively. The Data of Enthalpy, entropy and density of ammonia (NH_3), Aqua-Ammonia & R32 Refrigerants are listed in table 1.

Let, h1, h2 ,h3 ,h4 be specific enthalpies ; p1,p2,p3,p4 be pressure ; v1,v2,v3,v4 be volume ; at state 1,2,3 & 4 on the cycle respectively. X is dryness fraction of refrigerant after it leaves the turbine at stage 4.

$Wd_{pump} = \int(v)dp = v_1\times(p_2-p_1)$

$$\eta = \frac{Wd\text{net}}{Qin}$$

A) Calculations for Ammonia (NH_3)

$\mathbf{h_1 = 380.36}$

$Wd_{pump}=v_1\times(p_2-p_1)= 0.00159(1034.5\times10^3 -573.70\times10^3)=0.732$

$\mathbf{h_2=h_1+Wd_{pump} =381.092}$

$\mathbf{h_3= 1627.2}$

$h_4= h_f+(x*h_{fg})$ at Pressure corresponding to 8°C

$\mathbf{h_4=1551.74}$ ......($x=0.95$)

$Wd_{turbine}=h_3-h_4 =75.46$

$\mathbf{Wd_{net}=wd_{turbine}- wd_{pump} =74.728}$

$\mathbf{Q_{in}=h_3-h_2 =1246.108}$

$$\eta = \frac{74.728}{1246.108}$$

Efficiency = 5.99%

B) Calculations for Aqua-Ammonia

h_1= 267.60

$Wd_{pump}=v_1\times(p_2-p_1)$ = 0.00149(930.3×10^3-517.17×10^3) =0.615

$h_2=h_1+Wd_{pump}$ =268.215

h_3= 1781.0

$h_4= h_f+(x*h_{fg})$ at Pressure corresponding to 8°C

h_4=1641.76 ....(x=0.93)

$Wd_{turbine}=h_3-h_4$ =139.24

$Wd_{net}=wd_{turbine}- wd_{pump}$ =138.625

$Q_{in}=h_3-h_2$ =1512.785

$$\eta = \frac{138.625}{1512.785}$$

Efficiency=9.16%

C) Calculations for R32

h_1= 214.15

$Wd_{pump}=v_1\times(p_2-p_1)$= 0.00097(1735.3×10^3-1042.6×10^3)=0.672

$h_2=h_1+Wd_{pump}$ =214.822

h_3= 516.39

$h_4= h_f+(x*h_{fg})$ at Pressure corresponding to 8°C

h_4=498.33 ....(x=0.94)

$Wd_{turbine}=h_3-h_4$ = 18.06

$Wd_{net}=wd_{turbine}- wd_{pump}$ =17.388

$Q_{in}=h_3-h_2$ =301.568

$$\eta = \frac{17.388}{301.568}$$

Efficiency =5.76%

6. RESULTS AND DISCUSSION

Refrigerant	Thermal Efficiency (%)	Pump Work(kJ/kg)	Net Work Output(kJ/kg)
Ammonia	5.99	0.732	74.728
Water + Ammonia	9.16	0.615	138.625
R32	5.76	0.672	17.388

Table-2: Calculated results of selected working fluids

In this section the achivements of thermodyanamic anyalysis , techno-economic,environmental anyalysis of cycle cosidering all three refregerants are presented.

Table 2 shows the outcome from the calculations done. Primararly the pump work for the fluids which is required to supply the fluid form deep sea water to up surface is high for ammonia . Therefore,cost associated for ammonia wrt pumping will be more than other two fluids . Simulation based on chart-3 clearly shows that the net work output is highest for aqua ammonia and least for R32 (*the net work output is calculated cosidering flow of 1 kg of refregirant*). Chart-2 shows relation betwwen the net power output and the thermal efficiency of plant .When friction losses of pump and net work of pump is taken into cosideration the overall thermal efficiency of plant takes an important role while making decision for working fluid for plant. Thus, Chart-2 clearly shows that aqaua-ammonia has an excellent performance with high efficiency and net work done. Ammonia and R32 shares close relation between value of efficencies with ammonia having net work output higher than R32. Thus , regarding thermal performance aqua-ammonia is proved to have highest thermal performance characteristics.

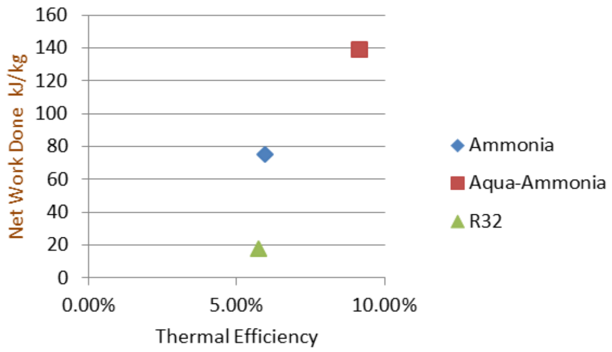

Chart-2: Simulated results of net work done and thermal efficiency

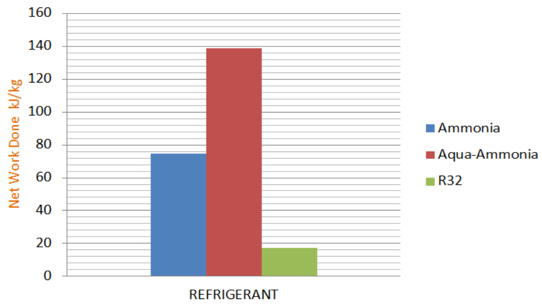

Chart-3: Comparison of net work done for selected fluids

Designing of heat exchanger(hx) requires knowledge of thermal conductivity to size a hx. The overall heat transfer coefficient of the condenser is higher for ammonia than for R32 [15], therefore cost associated with ammonia heat exchanger are forever lesser than aqua-ammonia and R32. Parallel flow hx is used for ammonia and aqua-ammonia system as in parallel flow hx the working fluid is in contact with high heat during entry therefore reducing viscosity of fluid which is desirable to scale back pumping power.

Refrigerant	Capital Cost USD/Net Power (kW)
Ammonia	21700
Aqua-Ammonia	16201
R32	16990

Table-3: Working fluid and capital cost USD/net power (kW) [21]

OTEC Power plant is a green project, self-powering and it does not use any fuel. Thus, major cost for the plant is cost of infrastructure. Table 3 gives data for the net Capital Cost USD/Net Power (kW). Based upon the data simulation from chart-4, it clearly shows aqua-ammonia as best working fluid in terms of thermal performance and having lowest net capital cost.

R32 and ammonia showed nearly same thermal performance however, R32 needs less capital cost to produce net work output than ammonia so here, R32 can be a good substitute to ammonia. R32 has a characteristic of smaller turbine size than ammonia, which will reduce the capital cost [17].

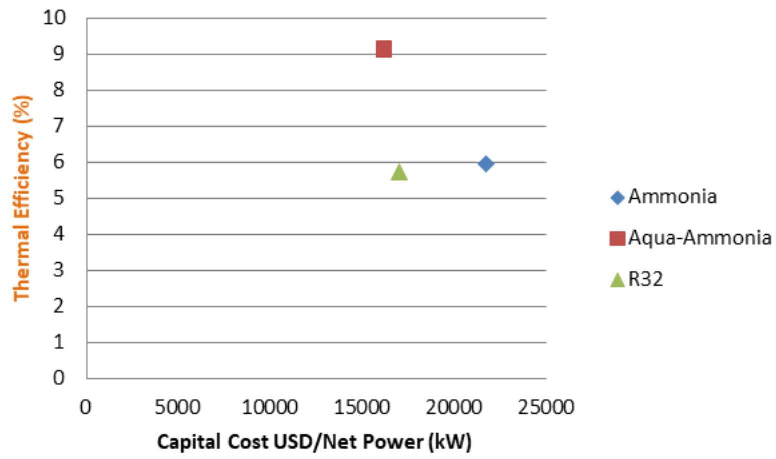

Chart-4: Relationship between efficiency and capital Cost USD/Net Power (kW)

Aqua-ammonia have less net cost and high efficiency as shown in the simulation chart-4 , however compared to different fluids aqua-ammonia adds up more cost for maintenance than R32 and ammonia. Aqua-ammonia is a pseudo-pure fluid i.e. homogeneous mixture of water and ammonia-water mixture requires a separator to ensure the turbine blade isn't affected by water vapour from the fluid.

When ammonia-water absorption machines are used as heat pumps, the main problems is be found in the components operating at a high pressure (generator-condenser) [18], therefore regular check-ups of piping and components are necessary that adds up in further labour value.

Refrigerant	Flammability	Toxicity	Ozone Depletion Potential (ODP)	Global Warming Potential (GWP)
Ammonia	Low	High	0	1.00
Ammonia-water mixture (0.9)	Low	High	0	1.00
R32	Low	Low	0	675

Table-4: Environmental parameters for working fluids [20]

Table 4 describes the environmental parameters that need to be taken under considerations while selecting a working fluid particularly for refrigerants. As the more value of GWP the more the gas will heat up surrounding as compared with CO_2. Here R32 has very high GPW as compared with other fluids, however as compared with different refrigerants which are not considered in this paper, R32 has lowest GWP and tagged as a green label fluid according to ASHRAE rating. R32 is least toxic and extremely tough to ignite at normal operating temperatures. Ammonia has no cumulative effects on the environment and a very limited (a few days) atmospheric lifetime [19]. Aqua-ammonia is less toxic as compared with ammonia because unvaried mixture of water. During working conditions leakage of ammonia based refrigerant may be quickly & easily detected by the use of burning sulphur candle which in the presence of ammonia will form white fumes of ammonium sulphite.

7. CONCLUSIONS

The current study investigated the performance parameters of working fluids such as thermal, economical & environmental parameters which play a vital role in selecting desirable or most suitable working fluid for OTEC plant. It is Clear from above discussions fluid selection process is a trade-off between thermodynamic, economical & environmental - safety properties [20]. The Results distinctly exhibits aqua-ammonia as the possible candidate to replace ammonia & R32 as the prime fluid as having the least cost and possessing highest efficiency between other fluids in study. As no working fluid is ideal, R32 leads in safety and environmental parameters than ammonia based fluids. Thus, R32 is undoubtedly best replacement for ammonia as non-corrosive and less maintenance required thus more plant life. Considering all studied parameters thus, R32 is chosen to replace ammonia refrigerant. Certainly for small MW capacity OTEC Plants if maintenance and safety is concerned one can definitely operate plant with R32 as a substitute for aqua-ammonia refrigerant despite having lower thermal performance than aqua-ammonia.

GWP and ODP can be reduced by combining two or more working fluids. Novel azeotropic mixture of R717/R170 is proposed for OTEC power plants to replace conventional working fluids. R717/R170 is an environmentally friendly working fluid with no ozone depletion potential and low greenhouse warming potential [2]. Future studies are needed on such types of azeotropic mixture of refrigerants, to ensure complete zero emission and zero damage to atmosphere, so that OTEC plants can emerge as a successful non-conventional source of energy replacement to fossil fuel based power plants and evolve as a reliable source of energy.

REFERENCES

[1] Walter Engels and Farshid Zabihian," Principle and Preliminary Calculation of Ocean Thermal Energy Conversion", ASEE 2014 Zone I Conference (University of Bridgeport, Bridgeport, CT, USA), ISBN: 9781479952342, April 2014.

[2] Nicholas Cox," A Novel Working Fluid for Ocean Thermal Energy Conversion ", Colling India magazine, pp.-24-28, April 2012.

[3] Ocean Thermal Energy Conversion - Makai Ocean Engineering, https://www.makai.com/ocean-thermal-energy-conversion.

[4] Graciela Rivera , Angélica Felix , Edgar Mendoza , " A Review on Environmental and Social Impacts of Thermal Gradient and Tidal Currents Energy Conversion and Application to the Case of Chiapas, Mexico", International Journal of Environmental Research and Public Health(ijerph), ; doi:10.3390/ijerph17217791 , 24 October 2020

[5] Christina M. Comfort(University of Hawai'i at Mānoa) and Luis Vega ," Environmental assessment for ocean thermal energy conversion in Hawaii: Available data and a protocol for baseline monitoring", Conference Paper, DOI: 10.23919/OCEANS.2011.6107210 , September 2011

[6] Yasuyuki Ikegami, Takeshi Yasunaga ,Takafumi Morisaki, "Ocean Thermal Energy Conversion Using Double-Stage Rankine Cycle" ,journal of Marine Science and Engineering(JSME),Vol-84 Issue-859, doi:10.3390/jmse6010021 ,March 2018

[7] S. M. Masutani(University of Hawaii at Manoa) and P. K. Takahashi, "OCEAN THERMAL ENERGY CONVERSION (OTEC)", Book Chapter Encyclopedia of Ocean Sciences , pp.1993-1999, DOI: 10.1006/rwos.2001.0031, December 2001

[8] L.A. Vega , "Ocean Thermal Energy Conversion Primer" , Marine Technology Society Journal 36(4) , pp.- 25-35 , DOI: 10.4031/002533202787908626 , December 2002

[9] Abdullah Mohammed Aldale(Department of Electrical Engineering/ University of South Florida) , "Ocean Thermal Energy Conversion (OTEC)",American Journal of Engineering Research (AJER) , Volume-6, Issue-4 , pp-164-167 , e-ISSN: 2320-0847 , 2017

[10] Arun Bangotra and Anshul Mahajan ," Design Analysis Of 3 TR Aqua Ammonia vapour Absorption Refrigeration System" , International Journal of Engineering Research & Technology (IJERT) , Vol. 1 Issue 8, ISSN: 2278-0181 , October - 2012

[11] "Ammonia As a Refrigerant: Pros and Cons" , Ammonia As a Refrigerant: Pros and Cons | Just Venting (goodway.com) , 1/28/2021

[12] Uehara, H.; Ikegami, Y. Parametric Performance Analysis of OTEC Using Kalina Cycle. ASME Jt. Sol. Eng. Conf. 1993, 60, pp.-3519–3525

[13] Taylor P. , and Sami S. M ," ORC for low temperature power generation with low GWP refrigerants", International Journal of Ambient Energy, pp.-37–41, March 2013

[14] IIAR Ammonia Data Book, December 1992 (Rev. May 2008), International Institute of Ammonia Refrigeration, Alexandria, VA, p. 4-11

[15] E.N. Ganic (Department of Energy Engineering University of Illinois) and J. Wu," COMPARATIVE STUDY. OF WORKING FLUIDS ~·· FOR OTEC POWER PLANTS", Technical report , Ocean Thermal Energy Conversion Program Argonne National Laboratory , January 1979

[16] Aashish Pawar, Rohit Patil ,Uchit Shah , "R32 the Future Refrigerant" , February 10, 2020
[17] Kim, N. J., and Chun W. " Using the condenser effluent from a nuclear power plant for Ocean Thermal Energy Conversion (OTEC)", 50 International Communications in Heat and Mass Transfer, 36(10), pp.-1008–1013,2009
[18] M. Shankar Babu, L. Devanand Prasad, K. S. Durga Prasad , M. Vikas, P.S. Kishore," Performance of Ammonia-water Vapour Absorption Refrigeration System" , Journal of Emerging Technologies and Innovative Research (JETIR) , Volume 6 Issue 4 , DOI: 10.1729|Journal.20486, April 2019
[19] American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Position Document," Ammonia as a Refrigerant", February 2017
[20] Jamal Nouman , "Comparative studies and analyses of working fluids for Organic Rankine Cycles – ORC", Master of Science Thesis, KTH School of Industrial Engineering and Management Energy Technology EGI-2012-086MSC, September 2012
[21] Norazreen Binti Samsuri,"A simulation study on performance enhancement of technoeconomic efficiency of ocean thermal energy conversion cycle using different working fluids", Master of Philosophy thesis , Malaysia-Japan International Institute of Technology , July 2017

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