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Investigation and Development of Waste Heat Recovery for Sea Water Desalination

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Abstract

For a ship in the deep sea, as an autonomous system, it is mandatory to effectively use the energy provided by the combustion of fuel to sustain this last for the duration of the trip. Previous research and technology developments have looked at recovering waste heat through engine cooling systems powering several on-board systems such as water desalination, and/or water heating. For this project, a flue gas heat recovery system will be investigated and the available heat recovered used as a heat source for seawater desalination on the ships. A calculation model will be generated and experimental validation will be required.

About 30% of the total combustion heat of an IC engine is carried away by the outgoing exhaust flue gases. This exhaust waste heat can be used for the purification of water. In the present work, a waste heat recovery cum water purification unit consisting of a horizontal tube submerged evaporator and water-cooled condenser was designed, fabricated, and integrated into a 3.5 kW variable compression ratio diesel engine to perform purification.

Keywords — *sea water desalination, waste recovery, desalination process, seawater purification.*

I. INTRODUCTION

Water desalination processes separate dissolved salts and other minerals from water. Feedwater sources may include brackish, seawater, wells, surface (rivers and streams), wastewater, and industrial feed and process waters. Membrane separation requires driving forces including pressure (applied and vapor), electric potential, and concentration to overcome natural osmotic pressures and effectively force water through membrane processes. As such, technology is energy-intensive and research is continually evolving to improve efficiency and reduce energy consumption.

Energy is an important entity responsible for economic growth, urbanization, industrialization, and improvement of quality of life in society. the abrupt rise in energy demand due to growing population and industrialization, depleting fossil fuel resources, and compilation with international protocols on the environment and climatic change has pushed the world to think about alternative sources of energy and methodologies for energy conservation

Seawater desalination has the potential to reliably produce enough potable water to support large populations located near the coast. Numerous membrane filtration seawater desalination plants are currently under construction or in the planning stages up and down California's parched coast, with the 50 million gallons per day (mgd) Carlsbad Desalination plant scheduled to be operational by 2016.

Reverse osmosis (RO) and Nanofiltration (NF) are the leading pressure-driven membrane processes. Membrane configurations include spiral wound, hollow fiber, and sheet with spiral being the most widely used. Contemporary membranes are primarily polymeric materials with cellulose acetate still used to a much lesser degree. Operating pressures for RO and NF are in the range of 50 to 1,000 psig (3.4 to 68 bar, 345 to 6896 kPa).

Electrodialysis (ED) and Electrodialysis Reversal (EDR) processes are driven by direct current (DC) in which ions (as opposed to water in pressure-driven processes) flow through ion-selective membranes to electrodes of opposite charge. In EDR systems, the polarity of the electrodes is reversed periodically. Ion-transfer (perm-selective) anion and cation membranes separate the ions in the feed water. These systems are used primarily in waters with low total dissolved solids (TDS).

Forward osmosis (FO) is a relatively new commercial desalting process in which a salt concentration gradient (osmotic pressure) is the driving force through a synthetic membrane. The feed (such as seawater) is on one side of the semi-permeable membrane and a higher osmotic pressure "draw" solution is on the other side. Without applying any external pressure, the water from the feed solution will naturally migrate through the membrane to the draw solution. The diluted solution is then processed to separate the product from the reusable draw solution.

Membrane Distillation (MD) is a water desalination membrane process currently in limited commercial use. MD is a hybrid process of RO and distillation in which a hydrophobic synthetic membrane is used to permit the flow of water vapor through the membrane pores, but not the solution itself. The driving force for MD is the difference in the vapor pressure of the liquid across the membrane.

Waste heat can also be employed for the purification of water. Potable water is absolutely necessary for the development of the human body. Moreover, the economic growth of any nation depends heavily on the availability of water resources. Out of the total water available on earth, only 3% is considered fit for drinking purposes. it has been noted that approximately 25% of the total population of the world does not have access to safe drinking water, many studies have been conducted by various researchers to utilize waste heat for water purification.

The waste heat from the thermal power plant was utilized for the optimization of water production and performance ratio of multi-stage flash distillation and multi-effect distillation plants designed a new sub-atmospheric pressure-based water distillation system. This system requires a low temperature to boil water and can run by using low-quality heat energy sources like waste heat of an ic engine. Recovered the waste heat from the cooling system and exhaust flue gases of a reciprocating natural gas engine and fed it to a small desalination system for purification of water. The advantages with this coupled unit were reduced freshwater cost, less thermal pollution, and significant power savings utilized waste heat of an engine to produce both power and water using submerged vertical tube evaporator designed a low-cost spray type evaporator in which saline water was sprayed into fine droplets for evaporation resulting in desalination of seawater. The annual production with 1 m2 of solar collector area was about 11.2 m3. therefore, many waste heat recovery systems have been designed in the past.

II. LITERATURE REVIEW

The main objective of this work is to design a water purification unit working on the basis of the waste heat of an IC engine; hence, literature available on the design of heat exchangers is also reviewed. Lastly, technological, economic, and social issues concerning distillation and water purification are retrospect.

Saidur et al. [2012] reviewed the new technologies developed for the recovery of the waste heat from IC engines. Various technologies like thermoelectric energy conversion using thermoelectric generators, Rankine bottoming cycle, and turbocharging using exhaust waste heat were discussed. The relation between environmental impact, exergy efficiency, and sustainability of a process was made. It was found that waste heat recovery based technologies are having a large potential for energy savings. These technologies will help to improve engine efficiency. Also, with the advancement in exhaust waste heat recovery techniques, the surge in fossil fuel demand and greenhouse gas emissions can be restrained which will restrict global warming in the long run. Moreover, by using such technologies the emission of pollutants like SO2 and NOx will decline.

Pandiyarajan et al. [2011] conducted an investigation using finned shell and tube heat exchanger for exhaust waste heat recovery from a diesel engine. The recovered heat was stored in a thermal storage medium. The experimental setup consisted of Kirloskar made four-stroke, twin-cylinder diesel engine having a rated power of 7.4 kW at 1500 rpm, an electrical dynamometer, finned shell and tube heat exchanger, and thermal storage system. Castor oil and paraffin were used as the sensible and latent heat storage mediums respectively. 320 grams of paraffin were filled in 48 cylindrical capsules having a diameter of 80 mm and a height of 100 mm each and were kept in a thermal storage tank. A pump was used to maintain the circulation of castor oil in the setup and thermocouples were used to record the temperature at various locations. The uniform temperature was observed throughout the storage tank due to the presence of stainless steel containers and high conductivity storage walls. Approximately, 10% – 15% of total heat was recovered by this system. The maximum heat recovered at full loading condition was 3.6 kW. Furthermore, an evaluation was made with respect to the heat exchanger and storage tank’s performance parameters like the amount of recovered heat, lost heat, rate of charging and charging efficiency. Results showed that the temperature of the exhaust gas can be decreased below 100 oC to recover more heat but this is possible only when there is no sulfur present in the exhaust gas. This may be due to the fact that by making the exhaust gas temperature below 100 oC the moisture present in the exhaust gas condenses and reacts with sulfur resulting in sulphonization which may corrode the heat exchanger tubes. Charging rate and charging efficiency were found to be increasing with the load.

Bari and Hossain [2013] conducted experiments to check maximum obtainable waste heat from exhaust flue gas of a diesel engine. The experimental setup consisted of a water-cooled, four-stroke, and four-cylinder diesel engine having rated torque 217 Nm at 2200 rpm, water dynamometer, fuel consumption meter, flow meter, thermocouples, and pressure gauges. For this work, two heat exchangers were bought from the market. Water was used as a working fluid in the heat exchangers. It was found that waste heat recovery results in 16% additional power generation. Moreover, the heat exchangers used were not optimized for the respective application. So, certain changes were made to advance the overall performance of the heat exchanging unit. Optimization was done with respect to the pressure of the working fluid and orientation of the heat exchangers. The additional power generation which was 16% before optimization changes to 23.7% after optimization.

Will [2012] analyzed the variations observed in simulation and test results for fuel conservation through the lubrication system of an IC engine. It was noted that the lubrication system of these engines is having a large potential for emission reduction and fuel conservation. The analysis was done keeping in focus the water condensation effects and transfer of heat to the lubrication oil from the engine. Different configurations for the recovery of the waste heat were developed. The results showed a 7% reduction in fuel usage. The emission of pollutants like HC, CO, and NOx was also decreased by 2%, 27%, and 19% respectively. In this work, a discussion was also made for the benefits and risks of systems working on the principle of waste heat recovery. Furthermore, it was found that there are many benefits associated with these systems like the reduction of wear in the engine, extension in the intervals of an oil change, and good performance of the engine.

He et al. [2011] improved the waste heat recovery from an IC engine by presenting a steady-state experiment, exergy analysis, and energy balance. The proposed thermodynamic cycle consisted of two cycles: the organic Rankine cycle, for recovering the waste heat of exhaust flue gas and lubricant; and the Kalina cycle, for waste heat recovery from the cooling system. The experimental setup consisted of Toyota made a gasoline engine, eddy current dynamometer, rotameter, oil tank, and temperature and flow measuring instruments. Suitable working fluids employed in high-temperature organic Rankine cycles were also proposed by authors through thermodynamic analysis. The waste heat recovery using the proposed combined thermodynamic cycle was found to be more than the traditionally available cycles. However, this combined cycle was considered to be feasible only for naval engines because of its space requirement and complexity. Moreover, the cost associated with the combined cycle was also high due to the addition of other components to be used in the Kalina cycle.

Lee et al. [2010] studied the effects of secondary combustion on efficiencies and reduction of emissions in the waste heat recovery system of a diesel engine. A secondary combustor consisting of Nichrome wires in a ceramic cylinder was placed on the engine outlet so as to burn the unburnt fuel leaving the diesel engine. Also, the heat from the exhaust gases and engine was recovered using fin-and-tube and shell-and-tube heat exchangers respectively. The experimental setup consisted of a three-cylinder and four-cylinder 930 cc diesel engine, a 12 kW electric generator, a secondary combustor, and two heat exchangers for heat recovery. The amount of heat recovered was known from water temperature coming from the outlet of both heat exchangers. It was noticed that by performing secondary combustion and recovering heat through effective heat exchangers the thermal efficiency of the system increases by 20% – 25%. Moreover, due to this utilization of waste heat, pollutants like NOx, COx, and particulate matter got reduced by 35%, 80%, and 90% respectively. It was found that the amount of recoverable heat energy increases with electric power generation in the generator. A whole efficiency (electric power generation efficiency and thermal efficiency) of the system reached a value of 94.4% by recovering heat and performing secondary combustion.

Bajwa et al. [2015] investigated the distribution of heavy toxic elements and uranium in the drinking water samples collected from four districts of South – West Punjab namely Bathinda, Mansa, Faridkot, and Ferozepur. It was found that uranium accumulated in the liver, kidneys, and bones is having both radioactive and chemical effects. Uranium concentration in this region (called 'Malwa') was found to vary between 0.5 µg/l – 579 µg/l with an average of 73.5 µg/l. The permissible limits of uranium as per WHO and AERB are 30 µg/l and 60 µg/l respectively. Investigation results showed that out of a total of 498 samples analyzed, 68% surpass the safe limit given by WHO and 43% exceed the safe limit given by AERB. Also, it was noted that the concentration of heavy metals viz. As, Pb, Ni, Zn, and Cr was above the safe limits given by WHO. These high concentrations might be due to natural geology, urbanization, industrial pollutants, or large use of pesticides and fertilizers in this region.

Sekhon and Singh [2013] investigated the heavy metals concentration in water samples collected from tube wells of 100 different locations of the Patiala district of Punjab, India. For analysis, the technique of atomic absorption spectroscopy was used. Samples were analyzed for six different heavy metals viz. Ni, Se, Pb, Cr, Al, and Cd. Then, samples were evaluated with respect to permissible limits defined by WHO. The content of Ni and Al was found to be quite high in most of the water samples but the content of other heavy metals like Se, Pb, Cr, and Cd was lower than the WHO defined drinking water limits. According to the authors, poor solid waste management, anthropogenic, and natural activities were the main reasons for water contamination.

Singh [2008] investigated the reason for cancer deaths in the 'Malwa' region of Punjab, India. A significant correlation between cancer mortality with pesticide residue in soil and water was found. A correlation between cancer mortality and cropping pattern was also observed. Also, areas under cotton crop indicated a positive correlation with cancer mortality. The report confirmed that the use of pesticides and fertilizers to increase the yield from the agricultural fields is the biggest reason for cancer in the state of Punjab. It was also found that agricultural fires during the wheat season carry pesticides away with it causing health problems in the region. The report suggested that the Government of Punjab should take initiative to make Punjab, a pesticide-free state and impose a ban on agricultural fires. One cancer hospital should be built in the 'Malwa' region of Punjab and water treatment plants (distillation units, ion exchange units, or RO units) should be installed in all Punjab villages.

Mehra et al. [2007] studied the content of uranium in the water samples collected from the Malwa region of Indian Punjab using the technique of track etching. It was found that the content of uranium in the water samples taken from Burj Harike and Barnala ranges from 5.41 µg/l to43.39 µg/l. These values were within safe limits defined by WHO and lower than the values noted in the water samples of Himachal Pradesh, India. The high content of uranium in some places might be due to the adjoining radioactive rich granites of Tusham Hills, Haryana.

Maheswari et al. [2015] conducted an experiment to desalinate water by using waste heat from the exhaust of an IC engine. The experimental setup consisted of a four-stroke, single-cylinder, water-cooled, 5 HP (at 1500 rpm) Kirloskar made diesel engine, an electrical dynamometer, and a distillation unit. The distillation unit was fitted in the path of exhaust flue gases. Submerged single pass evaporating unit, double pass water-cooled condenser and a saline water storage tank were also present with the unit. The design of the evaporator and condenser was done using the LMTD approach. It was found that the amount of desalinated water increases with the preheating of the saline water coming to the evaporator. Also, with load, due to more heat produced during combustion, the exhaust gases get heated up resulting in an increased collection rate of distilled water. Freshwater collection rate by using a water-cooled condenser with preheating at maximum loading was found to be 3.0 LPH.

Tanaka and Park [2010] utilized thermal energy in the form of waste heat from a portable electric generator as a heat source for multiple-effect based diffusion solar still. A heat pipe was used for this purpose. The experimental setup as illustrated in Fig. 2.18 consisted of saline-soaked wicks in the form of parallel partitions, condensing pipes, waste gas pipe, and tanks for water collection. Distillate productivity was increased repeatedly through evaporation and condensation processes in the still. It was found that approximately half of the total thermal energy from waste gas of the generator can be given to the first partition of the solar still. Results indicated that about 20 kg of distilled water can be produced using this still at waste gas flow rates of 10, 20, and 40 m3/h with an operation for 9, 5, and 3 hours respectively. The distillation water production rate was comparative to the maximum rate that can be obtained by using outdoor solar stills.

Sommariva [2008] utilized the waste heat from the thermal power plant to optimize water production and performance ratio of multi-stage flash distillation and multi-effect distillation based plants. The heat from different process steams in the power plant was made available to the brine solution. Using this heat, the performance ratio of the distiller was also increased resulting in lesser fuel used for the supplementary firing. Also, through waste heat recovery, the environmental impacts of the desalinating plant also got reduced.

Moore et al. [2008] described an innovative water distillation system that uses sub-atmospheric pressure and hence low temperature was required to boil water. This system was working on the basis of the Torricelli column principle which states that atmospheric pressure can bear a column of water 10 m high and above this height, the pressure will be very low. The experimental setup as shown in Fig. 2.19 consisted of two connected identical columns acting as evaporating and condensing units plus two pumps to pump saline water and freshwater. Saline water at a temperature higher than the freshwater was pumped to a height of 10 m. This water at sufficiently low pressure at the top vaporizes and flows through a pipe on top of the condenser and comes in contact with low-temperature freshwater in the condensing unit, thus got condensed and was collected in the freshwater tank. The system can be used to produce any amount of water by varying the height of columns and by varying temperatures. The disadvantages of this system were the cost associated with the heating purpose and the requirement of high capacity pumps for large applications.

Cardona et al. [2007] coupled a small-sized thermal desalination system with a single-stage seawater RO system. The system was fed by a reciprocating natural gas engine. The heat was recovered from both the cooling jacket water circuit and exhaust gas. The experimental setup as depicted in Fig. 2.20 consisted of a reciprocating natural gas engine, two heat exchangers, 12 effect-based distillation units of capacity 2000 m3/day, and a RO unit. Heat exchangers were placed in series for extracting heat from cooling water jacket and exhaust gases. It was found that the feed water before entry to the RO system was having a concentration of 38,000 ppm which reduced to 646 ppm after passing through the RO unit. This water was further mixed with distilled water coming from the distillation unit to obtain require quality water (TDS $\leq$ 500ppm, as defined by WHO) for drinking purposes. The advantages of this coupled system were reduced freshwater cost, less thermal pollution, and significant power savings.

Rahman et al. [2003] carried experiments on a vertical tube submerged evaporator. The shell diameter and height of the evaporator were 400 mm and 500 mm respectively. The experimental setup consisted of an evaporator, chiller water tank, heating medium tank, feed water tank, and a vacuum pump. In this experiment, the feed water was supplied by the feed water tank which flows vertically upwards inside the evaporator tubes and hot water from the heating medium tank flows on the shell side. Some feed water gets evaporated and was taken out by using the vacuum pump. Cooling water continuously flowed for condensation of the vapors. Modeling and simulation were also performed for this system by assuming steady-state conditions, one-dimensional fluid flow inside the tubes, and average properties. It was found that there was an increase in vapor generation with a surge in temperature of the heating medium. However, by increasing the flow rate of feed water the vapor production has decreased due to a reduction in the resident time. The freshwater production rate of this system was 144 kg/h. Hence, with this system, a freshwater quantity of 3.3 tons/day can be produced.

Kalogirou [2001] designed a low-cost spray type evaporator in which the saline seawater was sprayed into fine droplets for evaporation of the water. The experimental set up as illustrated in Fig. 2.21 consisted of an evaporating and condensing section, recirculation and seawater pumps, solar collectors, and spraying nozzles. In this setup, seawater was pumped through the condensing unit which condenses the water vapors formed during spraying. The heat released from water vapors was given to the saline water which raises its temperature. The hot saline water was then passed through the solar collector where its temperature got raised. Finally, it was directed to nozzles for spraying action. The water collected at the bottom of the evaporating unit was directed to the solar collector where it was heated again and redirected to the nozzles for spraying action. In this system, a small number of heat exchangers made of carbon steel pipes were used which were placed mainly on the condensing unit side. Using this setup, the annual production with 1 m2 of solar collector area was about 11.2 m3.

Kundu [2015] designed a beneficial unbaffled shell-and-tube heat exchanger for connection of longitudinal fins with a trapezoidal profile using parametric variation followed with Kern's method. In the experimental setup, two types of fin shapes rectangular and trapezoidal were longitudinally attached to the fin tubes. It was found that the rate of heat transfer increases and pressure drop decreases by using trapezoidal fins when the total volume of the fin over a tube was kept constant. This means that the heat transfer rates not only depend upon the arrangement of tubes but it also depends upon the geometry of the fins.

Zhang et al. [2013] did heat transfer analysis of a finned-tube evaporator working on an organic Rankine cycle for engine exhaust heat recovery using R245fa as a working fluid. The system consisted of a turbocharged diesel engine, finned tube counter flow evaporator, expander, generator, condenser, and a pump. The evaporator was having three zones namely preheated, two-phase and superheated zone. The working fluid after passing through the evaporator got expanded in an expander which further was linked to a generator. The evaporator was designed on the basis of the LMTD method. It was found that exhaust gas mass flow rate increases slowly with engine load but rapidly with engine speed but the exhaust temperature follows the reverse trend. Results showed that the mass flow rate of exhaust gas increases with engine power which in turn increases the overall heat exchange in the evaporator. The exhaust gas temperature was found to be decreasing as it passes through the superheated zone – a two-phase zone – preheated zone. Additionally, the preheated zone was found to have a maximum heat transfer area followed by a two-phase zone and a superheated zone.

Jamshidi et al. [2013] analyzed the improvement of heat transfer in the shell and helical tube heat exchangers. The effects of different fluid flow rates and geometrical parameters on heat exchange were found by using the Taguchi method. The heat transfer coefficients on the shell and tube side were noted using Wilson charts. The experimental setup consisted of copper made helical tubes having 10 turns with 9 mm inner diameter and 12.7 mm outer diameter. The shell was made of plexiglass having 14 cm inner and 15 cm outer diameters and having 25 cm length. Two parallel electric heaters having rated power 2000 W were used for heating water. The tube side fluid was hot water and the shell-side fluid was cold water. It was found that by raising coil diameter the Nusselt number increases and the overall heat transfer coefficient also increases. The maximum heat transfer rate was obtained by increasing the coil diameter, the distance between two coils, and mass flow rates of hot and cold fluids.

Markowski et al. [2013] investigated the influence of fouling on the recovery of heat in a network of shell-and-tube heat exchangers by assuming values for mass flow rate, inlet, and outlet temperature, and chemical composition for each process stream. Mathematical modeling was applied to the heat exchanger networks. It was found that by using the information collected from the past networks one can easily predict future changes and accordingly different methods can be employed to reduce fouling in the heat exchangers. A case study for optimal scheduling of cleaning interventions was also presented.

Pogiatzis et al. [2012] investigated two different methods available for cleaning of the heat exchangers which were subjected to both fouling and aging. An approach was also made with respect to cleaning intervals of the heat exchangers. Authors found that aging changes the soft gel formed due to fouling into a more hard form known as coke. This coke can be removed by using one of the cleaning methods discussed but not by the other one. In this work, a process model in which aging was considered by a simple two-layer model was constructed using a heat exchanger of counter-current type. It was noted that for the cleaning process of heat exchangers, a combination of mechanical and chemical processes was superior to mechanical cleaning processes alone.

Faizal and Ahmed [2012] studied the rate of heat exchange and pressure drop in a corrugated plate heat exchanger with variable warm water flow rates and spacing. The corrugation on the plate surface induces turbulence which resulted in increasing the heat transfer rate which was found by help measuring the temperature at the inlet and outlet of the plate heat exchanger. The experimental setup consisted of a corrugation pattern of 20 plates having a heat transfer area of 1.16298 m2. Water was used both as a hot and cold fluid. It was found that the overall heat transfer coefficient increases with increasing hot water flow rate for a given plate spacing. Also, the heat exchanger was found to be suitable with an effective rate of heat transfer for plate spacing of 6 mm. Moreover, with corrugation, the net heat exchange has been increased. This work will be useful for the design of heat exchangers with small temperature difference applications.

Medrano et al. [2009] investigated the process of heat transfer of five small heat exchangers during charging and discharging. The heat exchangers were working as latent heat thermal storage systems. The experimental setup consists of five small heat exchangers, a water pump, a thermostatic bath, a digital flow meter, and different valves to control the flow rate of water. On one side of the heat exchanger, commercial paraffin RT35 acting as a phase change material was used. On the other side, water was circulated for the purpose of heat transfer. The studied heat exchangers were compared with the average thermal power values obtained for the comparison of average power per unit average temperature gradient and per unit area. The values were found to be highest in a double pipe heat exchanger with graphite matrix-based phase change material. However, average thermal power was found to be maximum in the compact type heat exchanger.

Wang et al. [2009] investigated the enhancement of heat transfer of a shell-and-tube heat exchanger by installing sealers in the shell side placed in the gap between baffle plates and shell. Sealers were found to be cheap, easy to install, safe, and long-lasting. It was noted that three kinds of fluid flow modes exist in the heat exchanger's shell side. First, cross-flow through the tube bundle than the flow through the gaps of segmental baffles, and the last was shell-baffle leakage flow called short circuit flow. By installing sealers in the shell side, the short circuit flow was restricted and by doing so the fluid which earlier had not come in contact with the tube bundle for heat exchange now exchanges heat. So, by inserting sealers, the overall heat transfer rate has increased. Also, it was noted that by installing sealers, the heat transfer coefficient increased by 18.2 – 25.5%, and the overall coefficient of heat transfer increased by 15.6 – 19.1%. Although the pressure losses surged by 44.6 – 44.8% with sealer installation yet the increased power consumption can be compensated by a large increase in heat exchange which was far larger than the increased pumping power consumption. The sealers can be employed in new heat exchangers or can be installed in the existing installations easily.

Salimpour [2009] investigated coefficients of heat transfer of shell and helically coiled tube heat exchangers. For this study, three heat exchangers having varying pitches of the coil were selected. Both counter-flow and parallel flow configurations were used. 75 test runs were performed to calculate heat transfer coefficients for each test using fluid flow rates, plus inlet and outlet temperatures of shell-side and tube-side fluids. The experimental setup consisted of a centrifugal pump, a storage tank, an electrical heater, a coiled tube heat exchanger, a measuring pot, a manometer, thermocouples, and a flow meter. In this work, empirical correlations were proposed for the tube and shell side of the heat exchanger. A good agreement was found between the boundary layer based on existing correlations and the calculated coefficients of heat transfer for the tube side.

Kara and Güraras [2004] made a design model using the preliminary design of a shell-and-tube heat exchanger in which a single-phase fluid was flowing on both the tube and shell side. Initially, certain variables like type of working fluid, mass flow rates, fouling resistance, shell and tube material, along with inlet and outlet temperatures were needed to be provided by the operator. But, with the help of this program, the optimum area required for heat transfer, the complete dimensions of shell and tube bundle were determined keeping minimum possible pressure drop. Furthermore, the best heat exchanger was selected from 240 heat exchangers using this program. Moreover, this program can be extended to different heat exchanger configurations like multiple tube passes. The program was flexible to introduce other working fluids in place of water.

Lattemann and Hopper [2008] studied the impacts of seawater desalination on the environment. It was found that desalination is used to resolve the issue of potable water scarcity in coastal areas. Desalination systems are having both advantages and disadvantages. Some of the negative impacts are concentrate and chemical discharges, energy demand, and danger to marine life. Also, it is required that a proper disposal system should be made to concentrate and chemical discharges. Desalination systems working on the basis of renewable energy sources like solar, wind, biomass, or on waste heat recovery from stationary engines, power plants, etc. should be designed in the future.

Khawaja et al. [2008] reviewed the status and technological advancements in the area of seawater desalination. 75 million people in the World obtain freshwater by the desalination of brackish water or seawater. The authors noted that the multi-stage flash distillation and reverse osmosis are the two main techniques used mostly for the purpose of desalination. Further research and development with respect to economic aspects, water cogeneration systems, solar energy-based desalination systems, RO membranes, and resulting concentrate treatment will decrease the production cost of desalinated water.

Karagiannis and Soldatos [2008] reviewed various water desalination methods with respect to economic aspects. It was found that the production cost of freshwater through desalination depends on many factors like salinity in the feed water, type of energy source, the method adopted for desalination, and the total capacity of the desalinating plant. The production cost of freshwater using conventional energy systems ranges from 0.4 €/m3 to 3 €/m3. Using renewable energy sources, it can be as high as 15 €/m3. Although production cost was found to be much higher using renewable energy systems yet it can be compensated by lower gas emissions and environmental benefits. The authors found that there are two methods available for desalinating water viz. membrane processes (mainly reverse osmosis) and thermal processes (like multistage flash distillation and multi-effect distillation). Membrane processes are used by medium and low capacity systems, while thermal methods are used in medium and large capacity systems. IPSEpro, RESYSpro, and AUDESSY are some of the software tools developed for ecological, economic, and technical analysis of water desalination methods.

III. STUDY ANALYSIS

Seawater desalination is the removal of salt and impurities from seawater to produce fresh water. Our desalination plants do this via a reverse osmosis process.

Seawater is passed through a pre-treatment filter that removes large and small particles. The filtered seawater is then forced under pressure through special membranes whereby the osmosis process that normally occurs in nature is reversed. The pores in the membranes are so tiny that salt, bacteria, viruses, and other impurities are separated from the seawater. In essence, they act like microscopic strainers. About half of the water that enters the plant from the sea becomes fresh drinking water. The salt and other impurities removed from the seawater is then returned to the ocean via diffusers, which ensures it mixes quickly and prevents the marine environment from being impacted.

The desalinated water is then subject to further treatment to meet drinking water standards before it reaches our customers.

A. Sea Water Desalination Plant Process

The seawater desalination plant process is to convert seawater into freshwater. Firstly seawater (raw water) is delivered by the intake pump and sent into the desalination plant. Then raw water is pre-treated before entering into the SWRO system for there are many impurities in seawater, meeting requirements on RO feed water.

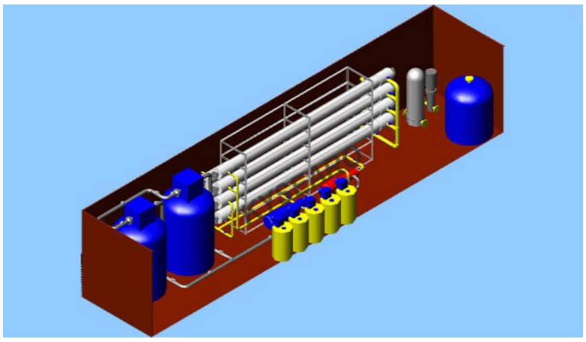


Fig.3.1 seawater desalination overview

SWRO plant is basically composed of the following systems, including intake system, pre-treatment system, seawater desalination RO system, energy recovery device, chemical dosing system, clean-in-place (CIP) system, and PLC controlling system.

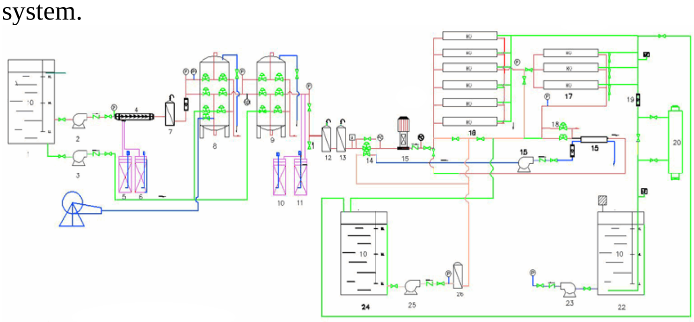


Fig.3.2 seawater plant process

a) Seawater Intake System

This seawater intake system is to deliver seawater into the SWRO plant. There are different kinds of intake methods based on hydrology water quality in the intake area, geology conditions, meteorological data, and natural disasters, such as Beach Well Intake, Subsurface Water Intake, and Open Sea Water Intake, etc.

b) Pre-treatment System

Inorganic suspended solids, sand, oil, clays, bacteria, and dissolved organic matters are susceptible to foul the reverse osmosis (RO) membranes. Required to conduct a good-quality pre-treatment process plays an important role in the operation of a seawater reverse osmosis (SWRO) plant, in order to prevent the fouling of the RO membrane. KYsearo seawater desalination plants usually adopt these pre-filters, including multi-media filter, activated filter, 10um, and 5um precision security filters. Please check How Multi Medium Filter Works in Desalination Systems.

The multi-media filter and activated carbon filter filled with refined quartz sand and cocoa-nut activated carbon respectively are to remove suspended solids, colloid particles, residual chlorine, microorganism, odor, and other particles in raw water. The coagulant is added by the dosing pump before raw water entering into the multimedia filter. Then flocculus formed by coagulant and colloids is removed through the filter, meeting the requirements on RO feed water (SDI15?5, turbidity?1NTU).

To prevent the particles in raw water and pipes from entering into the HP pump and RO module, two security filters are selected one after another as RO pretreatment. The precision of 2 sets of filters is 5?m and 1?m respectively. Under normal working conditions, filter elements should be changed in time when the pressure difference between the inlet and outlet of the filter is above 1 bar. Filter structure can allow changing filter element rapidly

.

c) Seawater Desalination RO System

RO system uses the semi-permeable membrane to remove organic material, colloidal particles, a bacterium from the feed water, producing desalinated freshwater. The semi-permeable membrane separates water and salt solution, water would permeate for the salt solution side under the osmotic pressure. If certain pressure larger than the osmotic pressure is applied to the salt solution, water would permeate in the opposite direction. This phenomenon is called reverse osmosis. RO permeate is purified, removing 98% TDS from the feed water. RO brine is concentrated with TDS about two times of the feed water.

d) Energy Recovery System

The function of an Energy recovery device is to reduce energy consumption and cost by recycling and reusing the pressure energy from the RO system high pressure concentrated seawater. Energy Recovery Device (ERD) is the key to energy-saving in the operation of any seawater reverse osmosis (SWRO) desalination products, in which PX Pressure Exchanger device is the most efficient solution available today and can reduce the energy consumption of seawater reverse osmosis (SWRO) systems by up to 60 percent.

Kysearo designs a high-performance seawater desalination plant for 20 T/D ~320 T/D. It’s our main line of business manufacturing for end-use or foreign agents. This scale tons don’t need too much electrical power. To save costs for customers, KYsearo’s engineer designs the process chart without energy recovery devices. Taking it would be more convenient change and low cost into account, we use spiral wound RO membrane, Generally DOW Filmtec RO membrane.

e) Chemical Dosing System

The chemical dosing system is a very important part of the whole water treatment system, including the coagulant and bactericide dosing device in the pretreatment, antiscalant, and reluctant dosing device before the 1st level RO, and the pH adjustment dosing before 2nd RO system. Each dosing device consists of a chemical tank, a dosing pump, and dosing pipes. All dosing devices are well designed and centrally installed for reliable and easy operation, supervision, cleaning, and maintenance.

f) CIP Cleaning System

With the better design for pre-treatment of RO device, it is no need to frequently clean membrane element. However, no matter how perfect the pre-treatment design is, there will be various kinds of pollutants forming at the surface of the membrane to some extent in the long-term operation process, which degrade membrane performance and raise the pressure difference between inlet and outlet. Therefore, except for the low-pressure flushing, it is requested to remove the dirt at the surface of the RO membrane by chemical cleaning regularly, as well as disinfection. The cleaning device consists of a cleaning tank, cleaning pump, and cleaning the filter. Here is the process How to Clean Seawater Reverse Osmosis System.

g) PLC Controlling System

Utilize integrated performance-testing software to conduct innovative industrial PLC control, which ensures to conduct online remote monitoring for process meters and system performance and enables remote notify users of system faults and maintenance requests in detail. KYsearo system has a one-click automatic switch machine function for easy-operating.

B. Features of Good Seawater Desalination System

The features of good seawater desalination system, especially end-users, they have little awareness and understanding about desalination technology, but really need one to work out freshwater resource problem.

1. Optimized exterior designs and internal structure.
2. Advanced material of all parts, especially core components
3. Complete desalination process
4. Simple operation, Easy to understand for end-users
5. Low maintenance costs
6. Long-term working life
7. High stability
8. High desalination rate up to 99.2%
9. Automatic operation with PLC control
10. High corrosion resistance

C. Function of Seawater Desalination Main Device

Reverse osmosis seawater desalination technology is widely applied over the world. There are several kinds of main devices in it, such as feed pump, multi-media filter, security filter, HP pump, RO system, etc. Here is their function introduction in detail as follows.

a) Feed Pump:

The feed pump is selected to provide sustained and stable feedwater flow and pressure. Famous Made-in-China CNP pump is strong anti-corrosion, high-efficiency, small noise, stable and reliable performance.

b) Multi-media Filter:

It is used for turbidity removal treatment of raw water. The filter equipped with two kinds of refined quartz and manganese sand adopts pressure filtration. It has the advantages of large cutting capacity, high filtration rate, and longer filtration period, which could effectively remove larger suspended solids and colloids to meet the requirements of the membrane inlet water quality (turbidity <1NTU) and to make the sure normal operation of post-treatment.

c) Ultrafiltration:

Ultrafiltration is a kind of membrane separation technology driven by pressure difference on both sides of the membrane. Under the effect of the static pressure difference, larger particles in raw water greater than membrane hole are trapped by the membrane, and small particles less than membrane hole can pass through the membrane, so as to realize the separation process. This separation principle is considered as mechanical screening. It has a small hole diameter and can intercept bacteria, viruses, colloids, oil, suspended solids, and large organic molecules, etc. Too large scale seawater desalination system, in order to protect reverse osmosis membrane and prolong membrane lifespan, it is also necessary to adopt ultrafiltration. The SDI of ultrafiltration production usually can reach less than 3, the production quality is better than that of a multi-media filter.

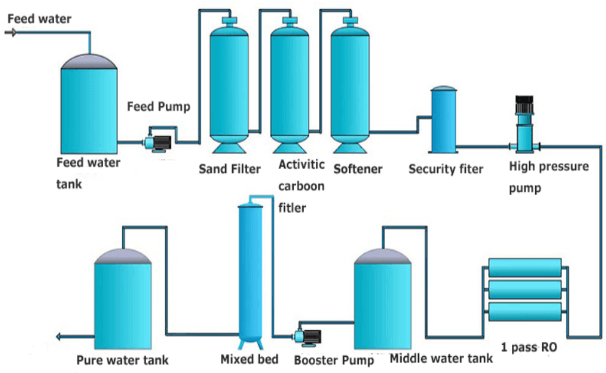


Fig.3.3 Ultrafiltration

d) Security Filter:

Security filters are installed at the entrance to the reverse osmosis equipment in order to prevent particles from entering the reverse osmosis membrane. As there is much TDS in the seawater, the material of the security filter adopts a 316L filter with 10um and 5um precision. Particles in the water greater than 5um are trapped by a 5um filter to ensure the HP pump, energy recovery device, and membrane module safe, reliable, and stable in the long-term operation.

e) HP Pump and Energy Recovery Device:

Reverse osmosis high-pressure pump is the main running equipment, which provides a power source for the operation of the reverse osmosis device. The energy recovery device is the device for recovering energy from high pressure concentrated seawater of the reverse osmosis system. The energy recovery of the advanced PX series of ERI companies can be up to 98%, which can reduce the cost of freshwater production by 60%. The high-pressure pump and energy recovery device provide the energy conversion and energy saving for reverse osmosis seawater desalination system according to water flow and pressure selection.

f) RO System:

The reverse osmosis membrane is the core of the reverse osmosis seawater desalination system, which is used to remove the ions, organic matter, colloidal particles, bacteria, and other impurities in the water, so that water is desalinated. The principle is that the semi-permeable membrane separates water and salt solution, water would naturally permeate for the salt solution side under the osmotic pressure. If certain pressure larger than the osmotic pressure is applied to the salt solution, water would permeate in the opposite direction. This phenomenon is called “reverse osmosis”. RO permeate is purified, removing 98% TDS from the feed water. RO brine is concentrated with TDS about two times of the feed water.

g) CIP System:

The cleaning system is mainly used for the protection of the reverse osmosis membrane of the seawater desalination system. The freshwater is automatically carried out on the reverse osmosis membrane for cleaning when finishing fresh water every time, and the chemical agents are used for cleaning and maintaining the reverse osmosis membrane to ensure the stability of the system. Please check How to Clean Seawater Reverse Osmosis System for more details.

IV. OBJECTIVES

The main objective of the project is to develop a seawater desalination machine by waste recovery method; Following are the set objectives of the proposed thesis work:

1. To find the amount of heat energy present in the exhaust flue gas of an IC engine that can be made available to perform distillation of water at varying loads and compression ratios, plus designing and fabrication of water purification unit on the basis of maximum recoverable heat.
2. To perform distillation of water using the designed water purification unit and calculate the distilled water collection rate at varying loads and compression ratios.
3. To test the collected distilled water for the presence of Physico-chemical parameters and heavy metals.
4. To compare purity levels of obtained distilled water and RO water and finding out the payback period of the proposed distillation unit at different working conditions.

V. METHODOLOGY AND SETUP

The main objective of this chapter is to design the evaporating and condensing unit for the water purification unit on the basis of maximum recoverable waste heat from the variable compression ratio engine. The chapter will also provide the details of the experimental setup, instrumentation, and operational procedure. In the end, details of the region from where drinking water samples were collected are given.

A. Recoverable waste heat

The amount of heat energy that can be recovered from the exhaust gas of an IC engine varies with the compression ratio, load, speed, and capacity of the engine. With the engine speed remaining constant, the quantity of recoverable heat energy changes only with the compression ratio and load

Variation of exhaust gas mass flow rate with a load on the engine is depicted in Fig. 5.1. It can be seen that the mass flow rate of exhaust gas increases with an increase in load on the engine. A surge is also observed with the compression ratio which is possible because of an increase in the swept volume of the engine with a compression ratio, which results in more exhaust mass flow rate at higher compression ratios.

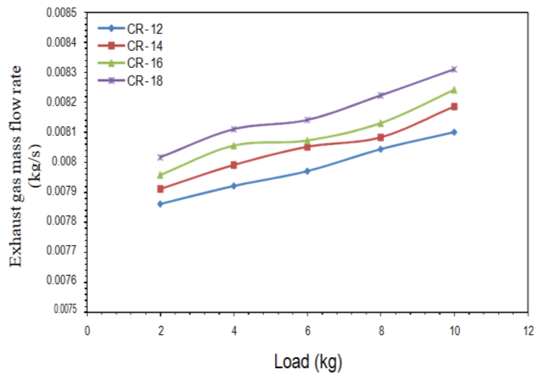


Figure 5.1: Variation of exhaust gas mass flow rate with the load on the engine

Figure 5.2 illustrates the variation of exhaust flue gas temperature at the inlet of the calorimeter unit with a load on the engine. An increase is seen in the temperature of the exhaust flue gas with the load. This may have become possible due to an increased amount of fuel injection at higher loads, resulting in more heat generation and thus the increase in temperature. The temperature is more prominent at lower compression ratios because at higher compression ratios, due to more expansion, swept volume increases because of which air intake into the engine increases, resulting in comparatively low exhaust gas temperature than the temperature at lower compression ratio.

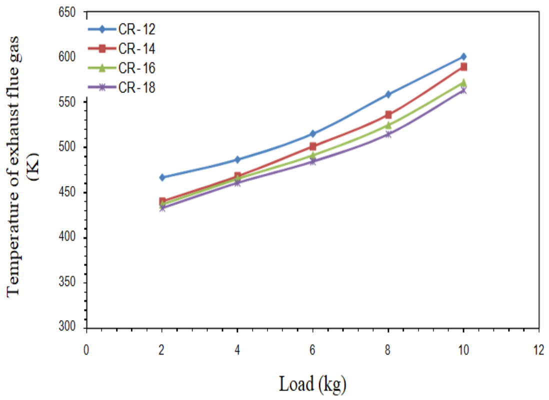


Figure 5.2: Variation of exhaust flue gas temperature with the load on the engine

The amount of heat that can be extracted from exhaust flue gas at different loads was calculated by using Eq.

$$Q_e = \dot{m}_e \times C_e \times (T_{ei} - T_{eo})$$

Figure 5.3 shows the variation of maximum extractable heat from exhaust flue gas with a load on the engine. The temperature at the outlet of the evaporator unit was considered to be ambient for the calculation of the maximum heat. The maximum extractable heat noted was 2.43 kW at 12:1 compression ratio and 10 kg load.

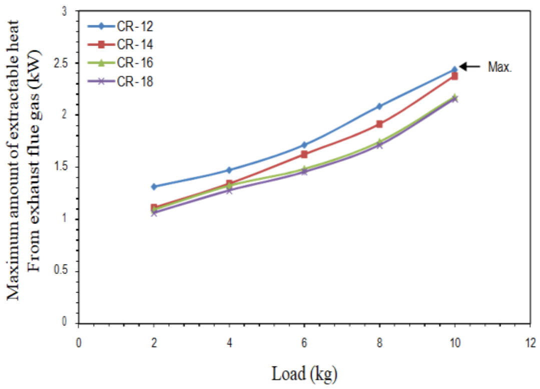


Figure 5.3: Variation of maximum extractable heat with the load on the engine

However, ambient temperature can never be considered as the flue gas temperature at the outlet of the evaporator, due to two following reasons:

- Both sulfur and water droplets are present in the flue gas. Due to the ambient conditions at the outlet of the evaporator, the water droplets get condensed resulting in the formation of sulphuric acid which may result in corrosion of the evaporator tubes made up of copper.
- The temperature of the exhaust gas should always remain higher than 100 oC as it is passing through the water which is at boiling temperature under atmospheric conditions.

Due to these reasons, the temperature at the outlet of the evaporator was considered to be more than 100 oC i.e. 120 oC. Figure 5.4 indicates the variation of actual extractable heat from exhaust flue gas by considering this temperature at the outlet of the evaporating unit. Now, the maximum actual extractable heat noted was 1.68 kW at the compression ratio 12:1 and 10 kg load. Temperature and fluid flow measurements were taken 30 minutes after the engine has been started to obtain stable readings.

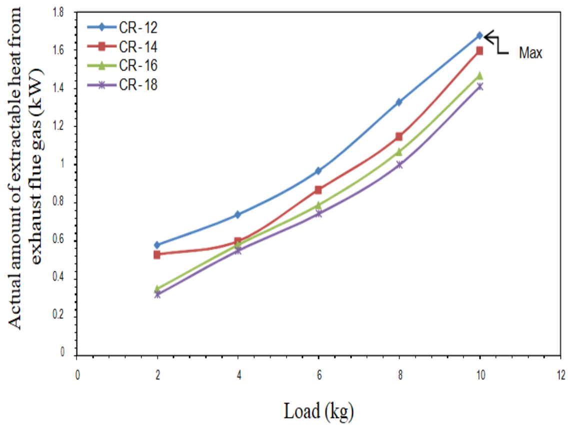


Figure 5.4: Variation of actual extractable heat with the load on the engine

B. Design of the heat exchangers

Rating and sizing problems are the most common heat exchanger design problems. Rating problems are used to find out the temperatures and rates of fluid flow at the outlet of the heat exchanger when the surface area of heat transfer and dimensions of the flow passage are available. However, sizing problems are used to find out the heat exchanger area, type of construction, flow arrangement, and shell and tube material to satisfy the requirements like hot and cold fluid inlet temperatures, rate of heat transfer, and pressure drop.

a) Evaporator design

A single-pass horizontal tube submerged evaporator (HTSE) was designed to avoid any performance loss of the engine due to restriction in the exhaust gas flow. The evaporator was designed by considering exhaust gas temperature at the outlet of the evaporator to be 120 oC. Also, an additional space to collect water vapors was needed in the evaporating unit. So, the copper tubes were fixed at the bottom of the evaporator making it a submerged type evaporator. The LMTD method was used for designing purposes. the following assumptions for the heat exchanger design:

i. The evaporator is operating under steady-state conditions.
ii. Heat generation in the evaporator is zero.
iii. An evaporator is an adiabatic system i.e. no heat transfer to the surroundings.
iv. For each fluid, specific heat at constant pressure remains constant throughout the operation.
v. There is no heat conduction longitudinally in the wall and fluid.
vi. If one of the fluid streams changes phase, it is considered to be occurring at constant pressure and temperature.

vii. The overall heat transfer coefficient remains constant all the way through the evaporator including in the case of phase change.
viii. The temperature of the fluids (hot and cold) is uniform over every cross-section of flow.

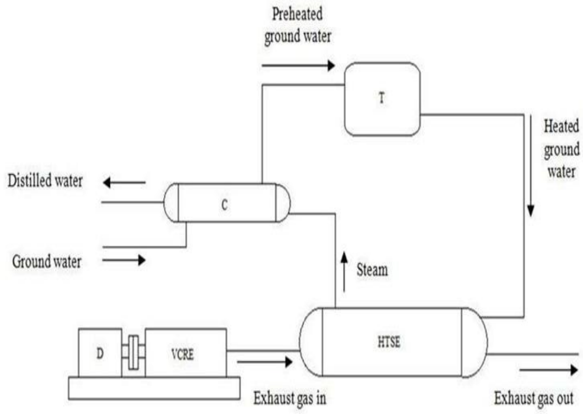
b) Condenser design

The steam formed in the evaporator was passed through the water-cooled condenser where its condensation takes place. In the condenser, groundwater was used to take up the heat from the steam and distilled water formed was collected in the distilled water storage tank. Groundwater after taking up the heat from the steam was passed to the hot groundwater storage tank. The condensing unit was designed on the basis of the evaporation rate. The design was based upon the LMTD method and the following were the assumptions made:

i. The condenser is operating under steady-state conditions.
ii. Heat generation in the condenser is zero.
iii. The condenser is an adiabatic system i.e. no heat transfer to the surroundings.
iv. For each fluid, specific heat at constant pressure remains constant throughout the operation.
v. There is no heat conduction longitudinally in the wall and fluid.
vi. If one of the fluid streams changes phase, it is considered to be occurring at constant pressure and temperature.
vii. The overall heat transfer coefficient remains constant all the way through the evaporator including in the case of phase change.
viii. The temperature of the fluids (hot and cold) is uniform over all cross-sections of flow. Heat load on the condenser

C. Experimental setup
a) System operation

The calorimeter unit integrated initially with the engine was disengaged. In place of this, an exhaust waste heat recovery unit was assembled in the exhaust gas path of the variable compression ratio engine. The schematic arrangement of the experimental setup is illustrated in Fig. 5.5. The heat recovery unit consists of a shell-and-tube single pass evaporator, made up of mild steel and copper respectively. The tube side fluid in this heat exchanger was exhaust flue gas and the shell-side fluid was groundwater.



D – Eddy current dynamometer VCRE – Variable compression ratio engine C – Water-cooled condenser HTSE – Horizontal tube submerged evaporator T – Hot groundwater storage tank

Figure 5.5: Schematic arrangement of the experimental setup

The preheated water from the water storage tank was fed to the evaporating unit. The supply of water to the evaporator was controlled by using a ball-control valve. In the waste heat recovery unit, heat from the exhaust flue gas was transferred to the surrounding groundwater resulting in evaporation of groundwater and steam so formed was passed through the stainless steel wire braided flexible pipe into the double pass shell-and-tube water-cooled condenser, where the energy from the steam was taken by the flowing water resulting in condensation of the steam. Distilled water formed due to this condensation process was collected in the distilled water storage tank. The hot groundwater from the condenser was stored in the storage tank. A drain valve for suitable drainage and other measuring instruments was provided in the evaporating unit resulting in condensation of the steam. Distilled water formed due to this condensation process was collected in the distilled water storage tank. The hot groundwater from the condenser was stored in the storage tank. A drain valve for suitable drainage and other measuring instruments were provided in the evaporating unit.

D. Components of the system
a) Variable compression ratio engine

Distillation of water was performed at the internal combustion engine (ICE) For this work, exhaust waste heat of an IC engine was used. In this engine, the compression ratio (CR) can be varied easily with the help of the tilting cylinder block arrangement. The loosening or fastening of six Allen key bolts and one lock nut changes the distance between the top dead center (TDC) and bottom dead center (BDC) due to which swept volume of the engine changes. Hence, the compression ratio changes with respect to Eq.

$$\frac{V_{sw}}{V_{cl}} = CR - 1$$

This dynamometer works on the basis of Faraday's law of magnetic induction. For load measurement, a strain gauge load cell was used. The shaft of the dynamometer moves across a magnetic field which produces movement resistance on the shaft resulting in load variations. The engine was integrated with the exhaust waste heat recovery unit for the purpose of water purification.

b) Horizontal tube submerged evaporator

A horizontal tube submerged evaporator was designed for the purpose of waste heat recovery from exhaust flue gas. The evaporator was a shell-and-tube type heat exchanger having seven copper tubes inside it. The shell of the evaporator was made up of mild steel. Hot water coming from the storage tank into this unit takes heat from the outgoing exhaust gas and gets evaporated, forming steam which further was condensed to form distilled water in the condenser. The evaporator and flue gas piping systems were well insulated by mineral wool having thermal conductivity 0.04 W/moC and reflective aluminum cladding to avoid heat losses to the ambient environment. The inlet and outlet temperatures of the exhaust flue gas passing through the evaporator were measured using K-type thermocouples. A drain valve was also provided in the evaporator for cleaning purposes.

c) Water-cooled condenser

A two-pass, single tube, the shell-and-tube heat exchanger was designed for the condensation of the steam coming from the evaporator. The fresh groundwater in the tube side takes up the heat from the steam resulting in condensation. Finally, distilled water was obtained in the distilled water storage tank. It was found to be fit for drinking purposes after mineralization. Groundwater after taking the heat from the steam was passed to the hot groundwater storage tank.

d) Piping for water purification unit

Pipes made up of different materials were used to supply steam and water to various locations in the water purification unit. The temperature of the steam leaving the evaporator unit was quite high, and a simple plastic pipe cannot serve the steam conveying purpose. So, stainless steel wire braided flexible pipe was used. The preheated water from the storage tank was supplied to the evaporator through a wired plastic pipe. In addition to this, simple plastic pipes were used to transfer fresh groundwater to the condenser unit for condensation of steam and preheated groundwater from the condenser unit to the hot water storage tank. Different pipes are used for conveying steam and water in the unit.

e) Hot water storage tank

Hot water after taking up the heat from the steam in the condensing unit was passed through a pipe to the hot water storage tank. This tank was used as a reservoir to store the preheated groundwater. It was fitted with a ball-type control valve which ensures the controlled supply (3 LPH) of preheated groundwater to the evaporator where its distillation will take place. The tank was made up of mild steel. The tank was made rust-free by coating it with paint.

f) Distilled water storage tank

The steam formed in the evaporating unit got condensed in the condenser resulting in the formation of distilled water. This distilled water was collected in the distilled water storage tank. The tank was thoroughly cleaned before experimentation to remove any contaminates initially present. The volume of collected distilled water can be found by measuring the height of water in this tank.

VI. ADVANTAGES

1. Reliable water source even under extreme weather conditions.
2. It is mobile which reduces the cost of transportation of the produced fresh water, as in the case of land-based desalination systems freshwater in the plant has to be transported from the production place to nearby cities by land. As transporting through the land is very costly, instead, we can install new freshwater platforms on the shore near the city as it is cost-effective for transportation by sea.
3. Construction of the desalination vessel is cheap because it is modified from a tanker, and erecting the platform is also cost-effective because it is near to the shore where the depth of water will be less.
4. These vessels make use of both the type of desalination methods of evaporation type and Reverse osmosis RO type. The vessels are driven by marine diesel engines that have a high jacket cooling water temperature sufficient for waste heat to generate freshwater through an evaporator type of desalination plant. Thus it is also an energy-efficient system using the waste heat from the running engine to generate freshwater.
5. These vessels generate their own power, which reduces transmission losses between the power grid and the desalination plant.
6. The ships can supply fresh water to one or more cities as it can be moored near the shore.
7. It reduces the number of chemicals used for the pretreatment of the water as the seawater

is not taken from close to the shore, which reduces pretreatment costs as the power, chemical, and waste disposal is far less in deep waters.

8. It has a minimal environmental impact compared to land-based desalination plants, as in land-based seawater desalination plants it discharges the waste brine solution nearby the shore which will contain the pretreated chemical, in turn, it will affect the local ecosystem. This does not happen in the SDV as its desalination process is carried out during its voyage so it reduces the pretreatment chemicals being used and the discharge of brine solution is being carried out at a constant discharge rate while the ship is en route. This kind of discharge will not affect the local ecosystem.
9. Its processing is fast and less complex than the land-based desalination system.

VII. CONCLUSION

As the world's population continues to grow, existing water supplies will become increasingly insufficient. As more and more water is required to meet mankind's needs, the desalination of seawater will become an increasingly important source of useable water. Any comprehensive plan addressing mankind's energy usage or ecologic impact must account for the effect of desalination; responsible development requires attention to the most energy-efficient methods of purifying water.

The aim of this thesis is to design a water purification unit working on the basis of exhaust waste heat recovery, Thermally-driven desalination technologies are frequently suggested for use with low-temperature waste heat sources, as the low temperatures are not useful for many industrial processes, but ideal for the lower temperatures found in desalination. In fact, such pairing with waste heat can even improve the electrical process: Diesel generators commonly provide electricity. About 40–50% of the energy output is low-grade heat that leaves the engine via the exhaust. Connecting a thermal desalination technology such as a membrane distillation system to the diesel engine exhaust repurposes this low-grade heat for desalination. The system actively cools the diesel generator, improving its efficiency and increasing its electricity output.

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