A Review into State of the Art Methods Developed for Purification of Water

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ABSTRACT
World today is facing an acute shortage of energy. Large amount of energy generated from different mechanical processes is dumped into the environment as a waste heat. This heat can be utilized for purification of water. Several researchers had worked in the area of desalination of water using waste heat from different mechanical systems. Many low cost water purifications techniques have been developed by the researchers in the past. The aim of this work is to review different methods/techniques developed for purification of water. The reviewed low cost methods will reduce the usage of excess energy in different water purification techniques like reverse osmosis, deionization etc. In future, renewable or waste energy based water purification systems can be developed. Moreover, the designing of systems based upon distillation for purification of water can solve water related issues in the '*Malwa*' belt of Punjab where the content of heavy metals and uranium was found to be quite high.

Keywords
Distillation; Energy; Waste heat; Water purification

1. INTRODUCTION
Energy is an important entity responsible for economic development of any country. Abrupt rise in energy demand due to growing population and industrialization, depleting fossil fuel resources and compilation with international protocols on environment and climatic change has pushed the world to think about alternative sources of energy and methodologies for energy conservation. Waste heat is the heat which is generated in a process by way of chemical reaction or combustion of fuel, and then dumped into the surroundings. This dumped heat can be used for some other applications thus giving economic advantages [1]. Water is vital for all human beings. It covers 71% of the Earth's surface. Nearly 96% of the water on Earth is found in seas and oceans which are not considered safe for drinking purpose due to presence of high salt content in it. Remaining, 1.7% is found in groundwater, 2% in glaciers of Greenland and Antarctica, and a small fraction is found in other large water bodies. Only 2.5% of Earth's water is considered as fresh water, out of which 98.8% is present in the form of groundwater and ice. Other 0.3% of water is found in lakes and rivers [10].

Safe drinking water is essential for human beings but approximately 1.2 billon people are still lacking access to safe drinking water [11]. This lack of sufficient water availability in a particular region has led to the problem of water scarcity. The reasons for water scarcity are many like inefficient use of water for irrigation and domestic purposes, poor wastewater and sewage management, release of effluents and chemicals to the rivers, industrialization, urbanization, and environmental pollution. The problem of water scarcity due to poor water quality and water pollution exists in India too. More specifically, according to recent reports, in the *'Malwa'* belt of Indian Punjab, the groundwater contains uranium and heavy metals in an amount more than the maximum prescribed limit defined by World Health Organization (WHO). Out of total 498 drinking water samples analyzed by the researchers, 68% exceed the safe limit given by WHO. Also, it has been noted that the content of heavy metals *viz.* As, Pb, Ni, Zn and Cr is above the safe limits given by WHO. These high concentrations might be due to natural geology, urbanization, release of industrial pollutants and large use of pesticides and fertilizers in this region [2]. One more study also confirmed that the use of pesticides and fertilizers is highest in Punjab and agricultural fires during the wheat season carry pesticides away with it and harm water bodies across the *'Malwa'* region [3].

Therefore, different techniques are needed to be adopted, to make the ground water fit for drinking purpose. Many techniques are available like Reverse osmosis (RO), Ion exchange and distillation. Both RO and ion exchange require power for their operation. Also, in case of RO, membrane has to be changed frequently. As explained above a lot of energy gets wasted from exhaust gas of internal combustion engine and in other processes. This waste heat can be used for performing distillation. The distillation units can be easily attached with stationary engines like ships or with generators. This research article reviews some of the state of art methods developed for the purpose of water purification.

2. DISTILLATION
In this technique, as shown in Figure 1, selective evaporation and condensation is performed for the separation of different components from liquid substance. Through distillation, water of highest quality which is free from all contaminants can be obtained [12]. However, distillation makes the water mild acidic. So, neutralizing materials like calcium carbonate (for pH > 6) or magnesium oxide (for pH < 6) are required to be added to increase the pH of distilled water. Moreover, distillation removes essential minerals like magnesium, calcium, potassium, sodium and fluoride too; therefore, mineralization is also needed to be done before water can be made fit for drinking purpose.

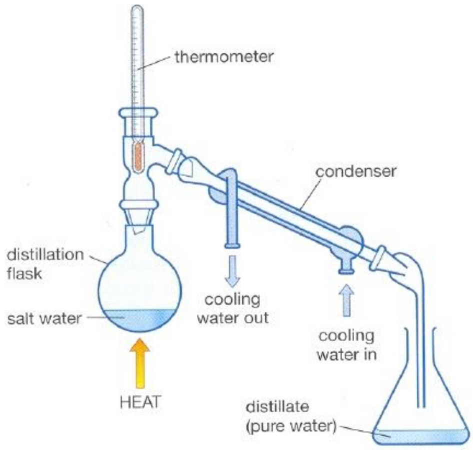

Fig 1: Distillation test setup for laboratory applications [12]

3. TYPES OF DISTILLATION

Distillation is widely adopted for the production of distilled beverages, crude liquid separation, air separation and water purification. In this subsection, different type of distillation techniques, their advantages and limitations, and uses are explained.

3.1 Fractional distillation

This type of distillation is used when the boiling points of different components present in a mixture are sufficiently close to each other. Repeated evaporation and condensation are performed in a fractionating packed column to perform distillation. This technique is mainly employed in the petroleum industry as it is used for the production of different petroleum components [13].

3.2 Steam distillation

This technique is meant for the distillation of heat sensitive compounds. The raw material mixture is heated and steam is bubbled through it. According to the partial pressure, the targeted compound will vaporize. The vaporized mixture can then be condensed for separation [14].

3.3 Vacuum distillation

Some compounds are having very high boiling points and these compounds cannot be evaporated easily. For such compounds, vacuum distillation technique is used. In this technique, the boiling pressure of the compounds is lowered. Once the pressure reaches the vapour pressure value at a particular given temperature, the evaporation commences and the rest of the distillation can be performed easily. This type of distillation is having large laboratory applications [15].

3.4 Molecular distillation

It is a kind of vacuum distillation performed at a pressure of 0.01 torr. At this pressure, the fluids are in free molecular flow regime which means the size of the equipment is comparable to the mean free path of molecules. In this technique, the evaporation rate does not depend upon pressure as no significant pressure is exerted by the gaseous phase on the substance to be evaporated. This technique is used in industries for purification of oils [16].

3.5 Membrane distillation

In this technique, the partial vapor pressure difference is used for the separation process. This pressure difference is triggered by the temperature difference. The separation is enabled due to phase change. The process uses a hydrophobic membrane that acts as a barrier for the liquid phase but allows the water vapors to pass through. This technique is generally used for seawater and brackish water desalination [17]. Figure 2 shows the membrane distillation process.

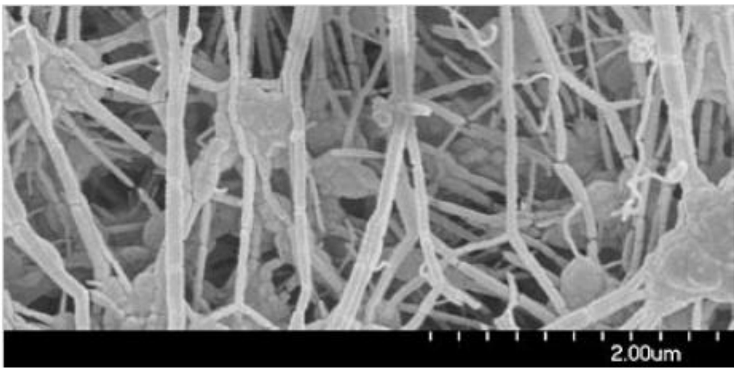

Fig 2: Membrane distillation process [17]

4. METHODS DEVELOPED FOR WATER PURIFICATION

Several researchers have developed many methods for purification of water. Some state of the art methods are given below:

4.1 Maheswari et al. set up

In this method, waste exhaust heat of an internal combustion engine was employed to desalinate saline water. The experimental setup as illustrated in Figure 3 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 exhaust flue gas path and consists of a submerged single pass evaporating unit, double pass water cooled condenser and a saline water storage tank. The design of the evaporator and condenser was done using LMTD approach. It was found that the amount of desalinated water increases with preheating of the saline water coming to the evaporator. Also, the amount of distilled water increases by increasing engine load because exhaust gases gets heated up due to more heat produced during combustion. Fresh water collection rate by using water cooled condenser with preheating at maximum loading was found to be 3.0 LPH [4].

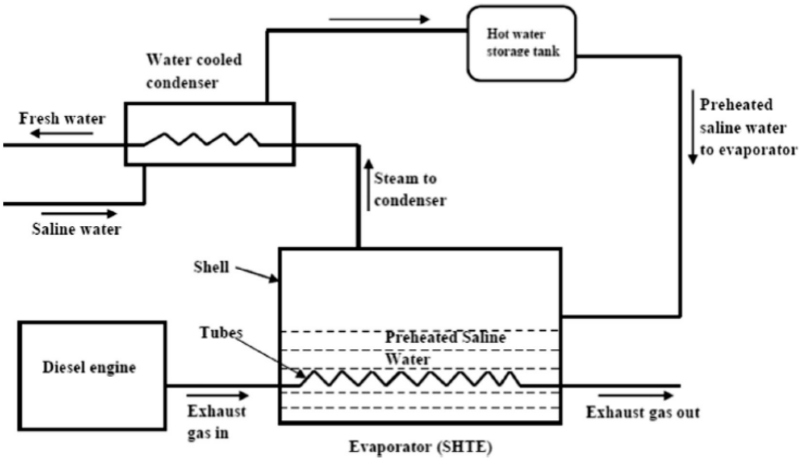

Fig 3: Water desalination unit using IC engine exhaust waste heat [4]

4.2 Moore et al. set up

A new water distillation system that uses sub-atmospheric pressure was made. With this technique, low temperature was required to boil water. This system was working on the basis of Torricelli column principle which states that atmospheric pressure can support a column of water 10 m high and above this height the pressure will be very low. The experimental setup as shown in Figure 4 consisted of two connected identical columns acting as evaporating & condensing units and two pumps to pump saline water and fresh water. Saline water at a temperature higher than the fresh water was pumped to a height of 10 m.

This water at sufficiently low pressure at the top vaporizes, flows through a pipe on top of the condenser and comes in contact with low temperature fresh water in the condensing unit, thus got condensed and was collected in the fresh water tank. The system can be used to produce any amount of water by varying the height of columns and by varying temperatures. The disadvantages with this system were the cost associated for heating purpose and the requirement of high capacity pumps for large applications [5].

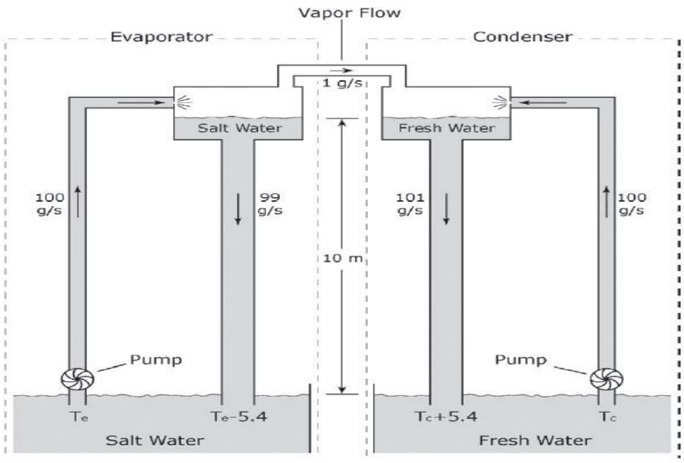

Fig 4: Torricelli column based water desalination unit [5]

4.3 Cardona et al. set up

In this method, a small sized thermal desalination system was coupled with a single-stage seawater RO system. The system was fed by a reciprocating natural gas engine. The heat was recovered from both cooling jacket water circuit and exhaust gas. The experimental setup as depicted in Figure 5 consisted of a reciprocating natural gas engine, two heat exchangers, 12 effect based distillation unit of capacity 2000 m^3/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 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 ≤ 500ppm, as defined by WHO) for drinking purpose. The advantages with this coupled system were reduced fresh water cost, less thermal pollution and significant power savings [6].

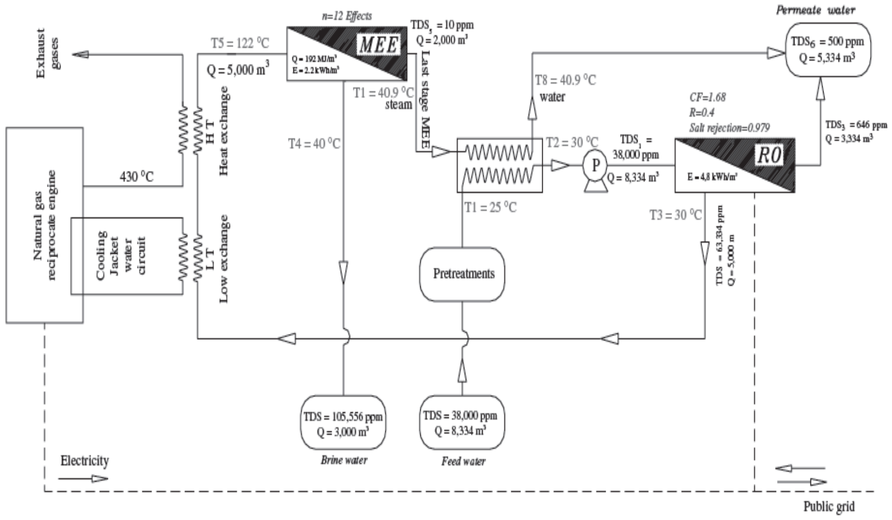

Fig 5: Desalination system coupled with a reciprocating engine [6]

4.4 Soteris A. Kalogirou set up

In this method, a low cost spray type evaporator in which the saline sea water was sprayed into fine droplets for evaporation of the water was designed. The experimental set up as shown in Figure 6 consisted of evaporating and condensing section, recirculation and seawater pumps, solar collector, 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 than 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 m^2 of solar collector area was about $11.2m^3$[7].

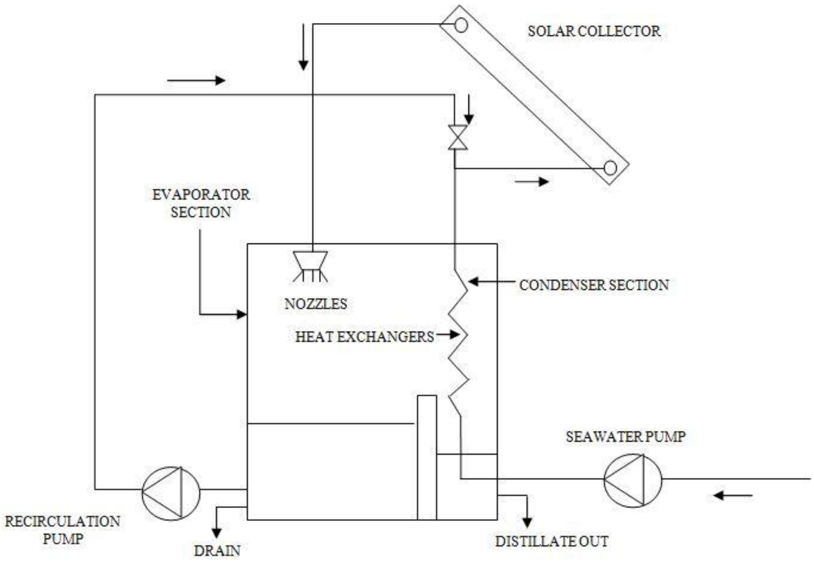

Fig 6: Desalination using spray type evaporator [7]

4.5 Rahman et al. set up

For water purification, in this method, experiments were carried on a vertical tube submerged evaporator. The shell diameter and height of the evaporator was 400 mm and 500 mm, respectively. The experimental set up 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 tubes of the evaporator 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 was continuously flowed for condensation of the vapors. Modeling and simulation were also done for this system by assuming steady state conditions, one dimensional fluid flow inside the tubes and average properties. It was found that there was increase in vapor generation with the increase in temperature of heating medium. However, by increasing the flow rate of feed water the vapor production has decreased due to decrease in the resident time. The fresh water production rate of this system was 144 kg/h. So, this system can produce a fresh water of 3.3 tons/day [8].

It has been found that distillation based water purification systems are having both advantages and disadvantages. The negative impacts include concentrate and chemical discharges, energy demand, and danger to marine life [9]. A proper disposal system is required to be made for concentrate and chemical discharge. However, water purification systems working on the basis of waste heat will decrease the operational cost of the plant. Additionally, renewable energy based water purification systems should be encouraged.

5. CONCLUSIONS

The objective of this work is to review different waste heat recovery or no-energy based water purification methods developed in the past. A detailed discussion into different developed systems has been made in this paper. Authors found that these waste energy or no-energy based systems generally work on the basis of distillation. The more advancement in distillation cum waste heat recovery based water purification methods will curb the issue of water scarcity, reduce thermal pollution, decrease energy demand and will provide water access to all the people around the world. In the future, more emphasis should be made to decrease chemical discharge produced by distillation and to develop renewable energy (solar, wind etc.) based water purification systems. Although, the cost of pure water production would be high with non-conventional energy based systems yet it could be compensated by lower gas emissions and other environmental benefits.

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