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A Review Study on Organic Rankine Cycles Coupled with Latent Thermal Energy Storage Systems Using Solar Energy as Heat Source

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ABSTRACT:The utilization of fossil fuels in energy sector has led the humanity to rethink and redesign the energy conversion systems in cleaner and cheaper ways due to unprecedented and unforeseen bad environment effects. Among all the renewable energy resources solar energy has provided the promising option to fulfil the energy demand. But due to the disparity between availability and demand the need of thermal energy storage is felt. Among all types of thermal storage systems viz. sensible storage, latent storage and thermochemical storage, latent thermal storage systems provide specific benefits of high charging density, isothermal operation and thermal stability etc. Latent thermal energy storage systems may be employed for storage of energy during the availability hours of energy source and supply the energy during the unavailability hours. In the proposed work a review study has been done on the various components of organic Rankine cycles (ORC) coupled with latent thermal energy storage systems using solar energy as heat source. There are three main components of aforementioned systems: solar evacuated tube collectors, latent thermal energy storage systems and ORC. Working principle of solar ETC and its advantages over other solar collectors has been reviewed. The various classifications of thermal storage systems have been reviewed and it was found that phase change materials based solid-liquid materials provide several advantages for thermal storage systems. Finally, the descriptions of various components of solar ORC have been done.

KEYWORDS: Evacuated Tube Collector (ETC), Latent Heat Thermal Energy Storage (LHTES), Phase Change Materials (PCM), Sensible Heat Thermal Energy Storage(SHTES), Thermochemical Energy Storage (TCES).

I. INTRODUCTION

Fossil fuel sources are the main sources of energy production for various needs of energy until 1965. Energy intensive production processes and industries require huge input of energy in various forms. There is an increased global energy consumption and emissions around 70 % and 60 % respectively if the energy consumption and efficiency trends are projected from the year 2011 to 2050. International energy agency (IEA) suggested an effective scheme of “2DS” which uncurtails the missions and visions for sustainable future and limiting the average global temperature rise within 2 ^{0}C with reduced CO_2 emissions [1]. With this date renewable energy sources have started to share the energy needs with fossil fuels [2]. Presently renewable energy sources fulfil around 6.7 % of the total global energy demands [3]. Among all the renewable energy sources, solar energy is the most promising option in fulfilling the local energy demands such as heating, cooling and power demands due to its huge potential (The Earth receiving 7500 times energy as compared to world’s total annual primary energy consumption of 450 EJ by solar radiation) and local availability [4]. Despite of such huge potential of solar energy, the major challenges in utilising it is lack of maturity of presently available tapping technologies and continuous availability. In order to have continuous supply of energy from solar resource, there has to be a storage unit which can store solar energy during sunny hours and release it during non-sunny hours as per the requirements.

Around 2 billion people worldwide do not have access to electricity and typically these populations live in remote areas which is far away from centralised electricity grids. The electricity transmission and distributors do not prefer to set up their systems as it is not economical advantageous[17]. Solar ORC is an appropriate option for providing combined heat and power in such remote areas. For distant regions with abundant sunshine, combination of ORC and photovoltaic panel (PV) can be a suitable option for fulfilling electricity demands[23]. Small scale solar ORC is well adapted for remote off-grid area of developing countries. The performance and design optimisation of a low cost solar ORC for remote power generation was investigated by Quoilin et al.[25] showing that an overall electrical efficiency between 7% and 8% can be reached with conservative hypothesis. Solar ORC can utilise freely available thermal energy from renewable energy sources and can store it. So, this facility of storage is key point of argument for solar ORC utility over solar PV systems. Thermal energy storage (TES) is able to ensure stable and continuous operation in case of scarce solar radiation and enables dispatchability in the generation of electricity. Costa et al.[26] investigated a solar salt for thermal storage system coupled with solar ORC and concluded the use of metal foams justifiable.

II. SYSTEM DESCRIPTION

There are mainly three subsystems of solar-ORC with latent thermal energy storage: evacuated tube solar collectors, thermal storage and power generation block. The evacuated tube collector subsystem receives solar energy and converts it into thermal energy of working fluid efficiently. The thermal storage subsystem stores thermal energy when it is in excess of what is required by power block and releases it when it is in deficit as required by power block. The power block converts the thermal energy in electrical energy with the help of organic Rankine cycle. The below figure depicts the various subsystems.

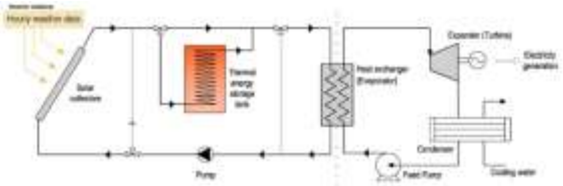

Fig.1. Schematic diagram of solar-ORC with latent thermal storage system[23]

A review study on the important components of above-mentioned system has been conducted in the present article.

III. SOLAR EVACUATED TUBE COLLECTORS (ETC)

Solar thermal collectors are used to capture the solar energy and converted into mainly thermal energy for further use of various applications like heating, refrigeration and air conditioning, water desalination etc. The solar thermal collectors are basically of two types concentrating and non-concentrating. The concentrating solar collectors use the concentrated form of solar energy with high solar intensity and hence achieve high operating range of temperatures. The examples of concentrating collectors are parabolic trough collectors, heliostat solar thermal collectors and Fresnel reflectors. The non-concentrating collectors use non-concentrated form of solar energy and hence achieve relatively lower operating temperature. The examples of non-concentrating collectors are solar water and air heaters and evacuated tube collectors. The evacuated tube collectors propose a better option in terms of cost and thermal efficiency for low temperature applications. The evacuated tube collectors use annular tubes in which vacuum is created in order to reduce conduction and convection losses[9].

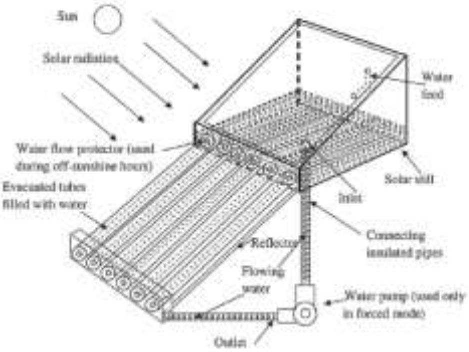

Fig.2. Schematic of ETC tubes in force mode of operation[28]

IV. THERMAL ENERGY STORAGE SYSTEMS

There are three main types of thermal storage systems for storing solar energy: Sensible heat thermal energy storage system (SHTES), latent heat thermal energy storage system (LHTES) and thermo-chemical energy storage system (TCES). The choice of thermal storage system depends upon the characteristics parameters of it. Some of the most important parameters are defined below[5] .

[1] Capacity of the storage system is defined as thermal energy stored in the system which is a critical function of the storage process, the medium and size of the system.

[2] Heat Storage Density (ρth) is defined as the ratio of heat stored per unit volume of storage medium. If Q is the heat stored in a medium having volume V, then heat storage density is given by:

$$\rho_{th} = \frac{Q}{V}\left(\frac{kJ}{m^3}\right)(1)$$

[3] Power (P) of the storage system is the measure of charging and discharging rate of thermal energy. If Q (kJ) is the energy stored at a time instant t then power can be defined as:

$$P = \frac{dQ}{dt}(kW)(2)$$

[4] Efficiency (η) is the ratio of energy provided to the user to the energy required to charge the system.

$$\eta = \frac{\mathrm{EnergyProvidedtoUser} \quad (\mathrm{kWhorkW}\ )}{\mathrm{EnergyRequiredtoChargetheSystem} \quad (\mathrm{kWhorkW}\ )}(3)$$

[5] Storage Period indicates the amount of time for energy storage. It can last from hours to months.Charging and discharging time is defined as time required for charging and discharging the system.

[6] Cost refers to amount of money required to operate the storage system (INR/kWh or INR/kW).
Based on the above parameters the thermal energy storage system may be defined and selected for the appropriate application. SHTES systems utilise the principle of heat storage and extraction due to the temperature difference of a substance of finite mass and specific heat. If a substance of mass m (kg) and specific heat at constant pressure cp (kJ/kg-^{0}C) undergoes a temperature difference of T_1 to T_2 during a process then the heat stored or extracted can be calculated as:

$$Q = \int_{T_1}^{T_2} mc_p dT \quad (kJ)(4)$$

On the other hand, LHTES system utilise the principle of heat absorption or liberation due to phase change of the substances. The materials used in such kind of systems are called as phase change materials (PCM). If a PCM of mass m (kg) and latent heat of phase change L (kJ/kg) undergoes a phase change then the heat absorbed or liberated during the process can be calculated as [6]:

$$Q = mL \qquad (kJ)(5)$$

The TCES system utilise the principle of heat absorption and release during a reversible endothermic/exothermic chemical reaction. Pressure and temperature of the space in which chemical reaction is taking place are the important parameters in defining the direction of chemical reaction [7]. If a reactant AB(s) decomposes into a solid A(s) and vapour phase B(g) with the application of external heat Q (kJ) then principally it can be written as:

$$n_{AB}.AB(s) + Q \leftrightarrow n_A.A(s) + n_B.B(g)(6)$$

Where n is the stoichiometric coefficient. After separating the products solid A(s) can be stored for a long time or transported for long distances. Since heat is added in the above reaction it is termed as charging mode. During the discharging mode, gas B(g) is passed through the solid A(s) which results in the formation of solid AB(s) and release heat Q(kJ) [8].

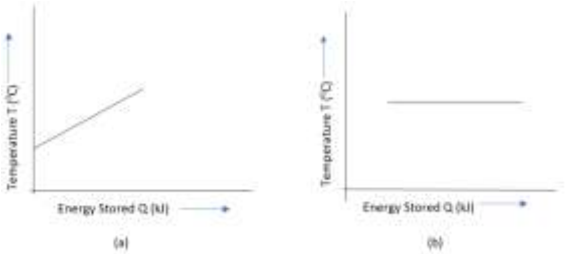

Fig.3. Basic concept of sensible heating (a) and latent heating (b)

During the operation of sensible heating of materials the temperature of the materials change, on the other hand the temperature of materials fairly remain constant during the latent heating of thematerials.The following table summarises the advantages and disadvantages of SHTES, LHTES and TCES.

Table 1: Comparison of SHTES, LHTES and TCES based on different criteria

S.No.	**Comparison Criteria**	**SHTES**	**LHTES**	**TCES**	**Reference**
1	Heat storage density	~50 kWh/m^3 ~0.02-0.03 kWh/kg	~100 kWh/m^3 ~0.05-0.1 kWh/kg	~500 kWh/m^3 ~0.5-1	[8]
2	Cost (€/kWh)	0.1-10	10-50	8-100	[7][5]
3	Storage time	Limited	Limited	Long Term	[8]
4	Principal of operation	Easy	Moderate	Difficult	[8]
5	Maturity	Commercialisation	Pilot plant	Laboratory	[8]

6	Transmission distance	Short	Short	Long	[8]
7	Heat losses	High	High	Low	[7][9]
8	Overall efficiency (%)	50-90	75-90	75-100	[5]
9	Common Materials	Sand, rock, brick, concrete, water etc.	Paraffins, water gel, hydrated	Potassium oxide, lead	[5]
10	Broad Applications	Solar heat utilisation, electricity storage, waste			[10]
11	Lifetime	Long	Limited due-to storage material	Depends on-reactant	[11]
12	Temperature Range (^{0}C)	-	-	20-200	[11]

From the above table it can be inferred that latent thermal energy storage using phase change materials are more suitable thermal storage option among the aforementioned options. While releasing the latent heat, the substance can have inter-transition between solid-solid, solid-liquid, solid-gas and liquid-gas phases. Solid-solid and solid-liquid phase change is usually preferred. Although solid-solid phase change has less specific and latent heat of fusion but it is advantageous because of no leakage and no encapsulation needed. At the same time solid-solid phase transition offers greater flexibility in design of containers for housing the PCM because of very minor volume changes during solid-solid transition. Although liquid-gas and solid-gas phase change has highest latent heat of phase change but it is not preferred due to the problems associated with handling vapour phase [7]. Consequently, it puts restriction in designing the containers for housing the PCM. Conclusively solid-liquid phase transition seems to be the most lucrative option among all the methods for thermal energy storage [9].

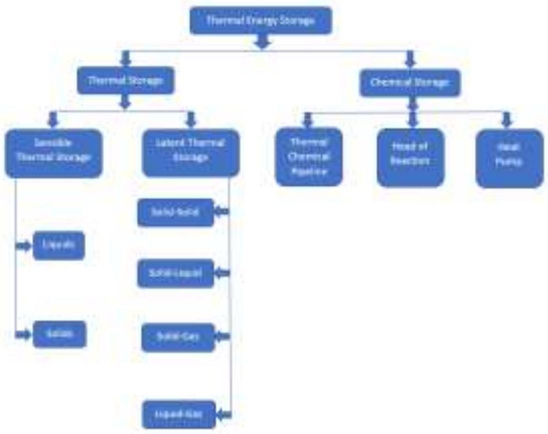

Fig.4. Classification of Solar Thermal Energy Storage Systems [5]

The materials/substances which are used to store and release the heat are called phase change materials (PCM). In most of the applications, PCMs are expected to possess some important desirable and non-desirable properties in order to store the heat effectively at low cost. The following table elaborates the various properties and their qualitative values for all the phase change materials.

Table 2: List of various properties of PCMs [5][12]

S.No.	**Kind of Property**	**Name of the Property**	**Definition of the property pertaining to PCM**	**Desired Qualitative Value**
1	Thermo-physical properties	Latent heat of fusion	Amount of heat absorbed or released during phase change of a substance	High latent heat of fusion to store/release high amount of heat as compared to sensible heat storage is desired.
		Thermal conductivity	Ability of the PCM to conduct heat	High thermal conductivity is desired in order to melt/solidify the PCM faster.
		Phase transition temperature	Temperature at which phase change of PCM takes place	Suitable phase change temperature is required according to application employed
		Heat transfer	Energy in transit due to temperature difference	High heat transfer rate is required to charge/discharge the PCM faster
		Density and volume variations	Variations in density and volume is defined as the change in density and volume due to phase change of the	Low density and volume variations during

		during phase change	PCM	phase change of the PCM is desired in order to achieve more flexibility in design of PCM container
		Density	Density is defined as the mass of PCM per unit volume	High density of PCM is required in order to reduce the size of PCM container.
		Vapour pressure	Pressure exerted by the vapours of the liquid PCM	Low vapor pressure of the PCM is required so that there is no need to employ very high mechanical strength PCM container
2	Kinetic and chemical Properties	Subcooling	Amount of sensible heat released from saturation liquid to a certain temperature	Very less or no subcooling is desired in order to keep the melting and solidification temperature range narrow
		Crystallization rate	Rate of formation of solid from liquid state during cooling	Sufficient crystallisation rate is required so that solidification takes place in the appropriate manner
		Chemical stability	Chemical inertness towards the various substances in the proximity of PCM	PCM are expected to have long term chemical stability in order to retain the properties during thermal cycling
		Compatibility with material of construction	Ability of PCM to be compatible with material of the construction	PCM materials should be highly compatible with container materials so that it does not face any change in its properties during charging and discharging

		Toxicity	Release of toxic substances	PCM should not release any toxic substance during its operation
		Fire hazard	Chance to initiate fire	PCM should not pose any fire hazard.
		Corrosion	Formation of oxides of PCM when exposed to environmental air	PCM should not participate in any corrosion/oxide formation reaction.
3	Economic Properties	Cost	Amount of money required to purchase PCM	PCM should be available at low cost
		Commercial availability	Availability of PCM either in nature or commercial market	PCM should be easily available in commercial markets
		Quantity available	Amount	PCM should be present in abundant quantity.
		Application range	Various applications in which PCM may be used to store heat	Application range of the PCM should be wide so that it may be used in various application

V. PHASE CHANGE MATERIALS BASED LATENT THERMAL ENERGY STORAGE APPLICATIONS

Although phase change materials are widely employed in various applications based on operating temperature range but there are some important potential applications identified in below headings[13][14][15].

[1] Solar Water Heating: The most important solar water heaters like solar flat-plate collector and solar evacuated tube collectors are better alternatives to gas/electric heaters as it can reduce around 50 tons of CO_2 emissions in atmosphere in the 20-year lifetime. These solar heaters can be coupled with phase change based LHTES in order to provide the continuous supply of hot water. As it is a well-known fact that solar radiation is not available during night time, cloudy or rainy days so PCM based LHTES provide energy in aforementioned time periods by releasing the energy which it had stored during the sunny hours. Hence PCM based LHTES act as a bridge between supply and demand for continuous power supply. Integration of PCM with such systems also improves the overall efficiency of the system as it is capable to absorb more heat when coupled with PCM. Also, it acts as a buffer thermal storage system which reduces the fluctuations in the temperature of water to minimal. The most common PCM for this application is paraffin wax (Melting point: 54 ^{0}C).

[2] Concentrated Solar Power (CSP) Systems: PCMs are commonly used in concentrated solar power plants. High heat storage and repeatability are the main motivating factors behind its usage in CSP plants. Various PCM's like sugar alcohols (melting point < 200 ^{0}C), molten salts (melting points > 300 ^{0}C) and metallic alloys (melting point > 500 ^{0}C) are widely used.

[3] Buildings: Per capita energy consumption is increasing day by day in order to avail more comfortable life. Hence number of utilities in buildings are increasing which results in more energy consumption. PCM can be integrated with building materials in order to provide thermal comfort as well as improve the overall performance of the building materials. Hence by incorporating the PCM in building materials will result in reduced power consumption while maintaining the same standard of living.

[4] Thermal Management of Batteries: Lithium-ion batteries are very popular among all the electrical batteries due to its high energy density and utility in portable electronic devices, battery powered tools and electric vehicles. But the performance of this battery is greatly affected by the operating temperature of the battery. For a better battery the rate of heat dissipation from the battery should be fast enough in order to avoid the thermal runaway condition of the battery. Hence PCM plays a very important role in thermal management of the battery by keeping the operating temperature range of battery in nominal range during both charging and discharging [16][14].

[5] Cooling Systems: The overall thermal performance of various cooling systems like buildings, food preservation, electronic equipment, refrigeration and air conditioning can be improved by employing the PCM. Various PCM in the melting temperature range of -37 – 4 ^{0}C are manufactured by Rubitherm technologies, Entropy Solutions LLC etc.

[6] Smart Textiles: PCM having melting temperature range between 28-35 ^{0}C are incorporated in textile fibre. When the body releases extra heat (heat which is greater than required to be in thermal comfort temperature range) then the PCM embedded in textile fibre absorbs it and undergoes phase change. On the other-hand when the temperature of the body falls below the comfort zone then PCM releases the heat and thus maintaining the stable thermally comfortable temperature range. The present demand of thermally stable textiles can be met by incorporating PCM in the fabrication of the textiles due to large thermal storage capacity and isothermal operation of PCM. The PCM embedded manufactured textiles offer good insulation and hence provide more thermal comfort as compared to without PCM textiles.

[7] Heat Recovery Systems: The exceptional latent heat storage capacity can direct PCM to be used in recovering the waste heat from various systems. It also bridges the gap between heat supply and demand.

[8] Nuclear Reactor: There is a very limited use of PCM in nuclear reactors due to some security reasons but still it can be used to store the energy during low demand and discharged during peak demand.

VI. ORGANIC RANKINE CYCLES

Steam Rankine Cycle (SRC) is probably one of the most mature reliable technologies for converting large scale thermal energy into useful power using water as a working fluid. Water itself is characterized as a favourable fluid with good thermal stability, low viscosity, cheap, abundant, efficient energy carrier, non-toxic and non-flammable with no environmental impacts[17]. One of the important applications of PCM based LHTES is to couple it with organic Rankine cycle (ORC). ORC cycle is similar to SRC as it contains all the essential components of SRC such as evaporator, expansion device, condenser and pump. It is mainly differentiated from SRC in terms of operating temperature range, power output and working fluid. While SRC uses water as a working fluid, on the other hand ORC uses organic compounds such as hydrocarbons, refrigerants, ethers and siloxanes etc. as a working fluid. ORC technology is as old as SRC but after the oil crisis and environmental issues during 70s and 80s, the development in this technology grew at a faster rate in various aspects such as novel configurations like cascaded cycle, alternative organic fluids such as zeotropic mixtures[1] and novel applications like use of ORC in automobiles[18]. The flowing table summarises the advantages and disadvantages of both ORC and SRC.

Table 3: Comparison of SRC and ORC based on their advantages and disadvantages[1]

S.No.	Steam Rankine Cycle (SRC)	Organic Rankine Cycle (ORC)
1	Advantages • Cheap and plentiful working fluid • Lower mass flow rate and smaller pump power consumption	Advantages • Versatility in terms of heat sources (solar, geothermal and industrial waste) • Small size due to high fluid density • Alleviation of safety concerns due to low pressure and temperature of working fluids. • Low capital and maintenance cost due to superheated condition after expansion and safe operation of expander. • Simpler expander design (one or two stage)

		• Low temperature heat recovery once-through boiler
2	Disadvantages • Lower thermal efficiency at lower exhaust steam temperature (Below 370 ^{0}C) • Bulky equipment due to high specific volume of steam • High capital cost, safety concerns and complex system due to requirements of high temperature and pressure (500 ^{0}C and 60 bar) • High maintenance cost due to erosion and corrosion of blades caused by steam droplets. • Complex multistage and bulky expander design • Mandatory air removal in a condensing mode with sub-atmospheric pressure	Disadvantages • Higher mass flow rates and larger pump power consumption • Lower efficiency at higher temperature (above 450 ^{0}C)

VII. ORC LAYOUT

The ORC configuration is similar to SRC, though, it is further simplified as there is no need of separate preheaters, evaporators and superheaters. Only one heat exchanger is sufficient to provide the required steam for further usage[19]. The following figure depicts all the components of simple ORC operated with low grade heat source such as solar energy, biomass, geothermal and waste heat.

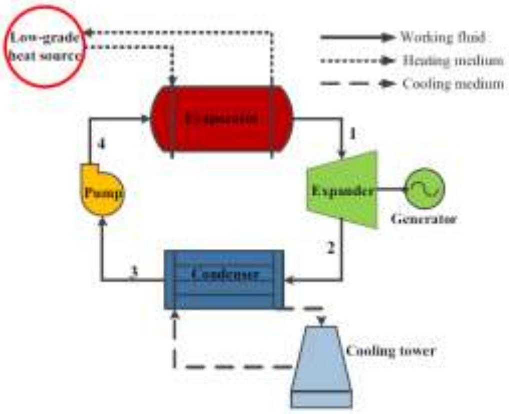

Fig.5. Simple ORC configuration with essential components[1]

The flow processes across the ORC components are explained as following:

1-2: The high-pressure vapours of organic fluid undergo isentropic expansion in which its thermal energy is converted to mechanical energy of the shaft by the expander. The then converted mechanical energy is utilised in running an electrical generator which is coupled with shaft of the expander to generate electrical energy. The electrical energy is further consumed for various purposes.2-3: The exhausted low-pressure vapours from expanders are condensed to liquid by cooling medium such as water or air. 3-4: The low-pressure working fluid is then pumped back to evaporator pressure.4-1: The fluid is then vaporised by utilising the heat form low grade heat sources and the cycle continues.

The corresponding temperature-entropy (T-S) diagram is shown below.

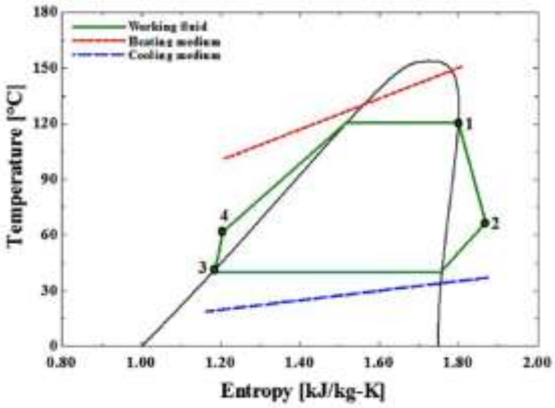

Fig. 6.T-S diagram of simple ORC cycle[1]

VIII. WORKING FLUIDS FOR ORC CYCLES

Selecting proper working fluid for the ORC is very important exercise as it affects the various operating, environment and safety related parameters like overall system efficiency, stability and environment and safety. Organic fluids have large molecular weights, low boiling pressure and temperature. The below figure depicts the slope of T-S diagram and hence characterises the organic fluids in three categories viz. dry, isentropic and wet fluids. If the slope of T-S diagram is positive then the fluids are considered as dry, if negative then fluids are considered wet and if zero then fluids are considered as wet fluids.

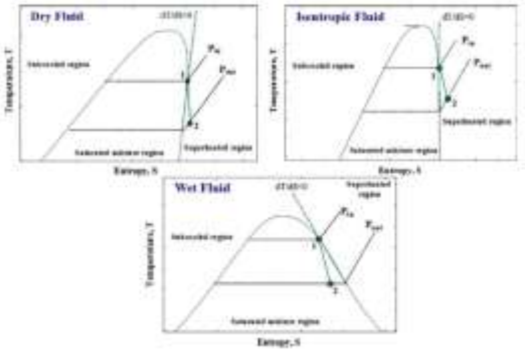

Fig.7. Figure classifying dry, isentropic and wet fluids based on slope of T-S diagram[1]

Apart from this other thermophysical properties should be considered in the selection of the organic working fluid. The flowing table lists some of the important thermophysical properties and their desirable characteristics.

Table 4: Some important properties and desirable characteristics of organic working fluid[1]

S.No.	Property	Desirable Characteristic
1	Latent heat of vaporisation	Low value of latent heat of vaporisation is preferred with low grade waste heat sources. At the same time the phase change -phenomena at variable temperature is preferred in order to match the pattern of temperature profile with that of heat source and consequently reduce the irreversibility [20][21].
2	Specific volume	Low specific volumes (high vapour density) are perhaps most important advantage of the organic working fluids which results in low evaporator and expander sizes and consequently make them cost-effective.
3	Critical temperature	If the critical temperature of the working fluid is close to the maximum temperature of the heat source then cycle configuration delivers maximum efficiency[22].
4	Thermal	In order to avoid decomposition of working fluid under high

	stability	temperature and pressure, it is desirable that working fluid should have thermal stability.
5	Environmental impacts	The working fluid should follow the current and possibly future environmental protection standards and regulations by having zero Ozone Depletion Potential (ODP), Minimal Global Warming Potential (GWP) and Low Atmospheric Lifetime (ALT).
6	Safety	It is desirable to use non-flammable and non-toxic working fluid in order to provide safety to working personnel.
7	Molecular weight	It is inversely proportional to the specific enthalpy drop across the expander. So, the larger the molecular weight the smaller the specific enthalpy drop and consequently the lower the number of stages required for the expander which reduces the cost and complexity.
8	Material compatibility	The organic working fluid should have non-corrosive and non-eroding characteristic to the most common engineering materials that are used fabrication of expander, heat exchanger, seals etc.
9	Viscosity	A low order of viscosity in both liquid and vapour phase is desirable in order to minimise the heat exchanger and pipe frictional losses.
10	Cost and availability	It should be easily available at low cost in the market.

It is very difficult to find all the above-mentioned properties in a single working fluid and hance there is a trade-off between the desirable properties which depends upon application.

Lizana et al. [23] explored one of the important applications of latent thermal storage systems. Mathematical modelling of low temperature solar ORC (80 0C to 140 0C) coupled with latent thermal storage system and low-cost solar evacuated tube collectors as heat source was done. TRNSYS and ASPEN software were used to simulate the solar energy balance and ORC system performance respectively. The results showed that by incorporating latent thermal storage tank there was 54 % of useful collector gain with the higher and narrower temperature range in the evaporator.

Tartiere et al. [24] analysed the development of ORC market over the years, with present cumulative installed capacity of 2.7 GW. The evolution of the ORC market has been discussed considering the present installed capacity, historic data and macro-economic trends. Finally, keeping waste heat recovery applications as priority for analyses, future perspectives and growth potential of ORC market has been analysed.

An overview of different applications of ORC like utilisation of geothermal, waste heat recovery etc., market review including cost figures for several commercial ORC modules and manufacturers and in depth review analyses of the technical challenges related to technology has been presented by Quoilin et al. [25]. For moderate power ranges and low temperature applications such as low temperature waste heat recovery or geothermal ORC are more appropriate option than SRC. Analysis of available market data inferred that actual plant size is limited principally by a minimum power output of few hundreds of kWe.

A comprehensive review of ORC including the cycle configurations, working fluid selections and expansion machines have been done by Rahbar et al. [1] . Majority of review studies were devoted to selection of suitable working fluids for various applications for thermodynamic modelling and optimisation of ORC performance metrics. R134a, R123 and benzene are some of the best fluids for temperature ranges of 150 ^{0}C, 150 ^{0}C- 250 ^{0}C and 250 ^{0}C- 400 ^{0}C respectively. Some studies were also conducted about design, modelling and experimental testing of the expanders. It was found that volumetric expanders (scroll) were used widely.

IX. CONCLUSION

The solar energy with storage facility can provide uninterrupted power supply. Among all the thermal storage methods latent heat thermal storage using phase change materials is a lucrative option for storing thermal energy because of high energy storage density, isothermal operation etc. Among most of the applications of thermal storage ORC is one of the emerging options for generating electricity. For the remote areas where the grid accessibility is not possible the solar-ORC coupled with latent thermal storage facility is a promising option for electricity supply.

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