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REVIEW OF ORGANIC RANKINE CYCLE USED IN SMALL- SCALE APPLICATION

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Abstract:
Organic Rankine cycle an alternative way of generating energy from waste heat, fuel and gases at low-temperature. Method (ORC) proved successful and high efficiency to reduce environmental pollution, fuel consumption and convert low to medium heat sources. The paper will be presenting a review investigation on the organic Rankine cycle(ORC), cycle Background, (ORC) configuration, and selecting of working fluids and experimental studied of expansion apparatuses, which are classified into two type volumetric type such as (expander of rotary vane, scroll, reciprocating piston expander and screw) velocity kind (for example axial and radial turbine). Heat exchanger and expander apparatuses are considered economically expensive parts in (ORC).

Keywords: ORC; Working Fluids; Expander; Application; Rotary Vane.

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1. Introduction

Recently, the demand for energy has increased and the adoption of fossil fuels method for generating electric power, so the prices of electricity sales according to the global trend increased by 30% in 2009. Research has been developed on work (ORC) around the world [1]. They presented review on (ORC) applications that used the heat from waste heat, engines, geothermal energy and solar. They used of internal combustion engines to convert fuel into mechanical energy. The results show thermal efficiency ranging from (15-32%). When used R-134a the amount of heat released (1.7-45) kW at temperatures 101.3°C above 280°C when used hexane reverse R-245fa performance was poor [2]. They noticed from the results that the efficiency is greatly depending on the proportion of the pressure in the expander in addition to the inlet temperature of the expander. Adopted in his work on energy analysis. They concluded that the working fluid R-134a was suitable for the (ORC) at low temperature [3]. They suggested working fluids at high temperatures for the (ORC) such as "Alkanes, aromates and linear siloxanes". The ranges of temperature (250-300) °C. They found the best working fluids in all cases "cyclopentane"[4]. They used refrigeration working fluids good R-1233zd instead of R-245fa. Found a higher efficiency for the cycle 8.7% compared to a liquid R-245fa at low temperature [5]. Factors that affect the thermal efficiency are the Condenser's and the solar collectors' temperature and the effect of the Condenser's temperature is temperature greater than the solar collector's temperature. They used

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evacuated solar collector. The performance of ORC was been compared with solar cell [6]. They studied the effect of mixtures on the (ORC) such as zeotropic mixtures. They found the increase in electric power around 12.3% and the increase in efficiency by 15.7% [7]. Worked to study the impact of environmental factors for example the solar radiation's intensity, ambient temperature, angle of solar radiation wind speed and fluid flow rate. They concluded that the increment in the temperature of ambient reduces the solar radiation's angle and the intensity of solar radiation [8]. This paper review of the (ORC), components of the (ORC), the selecting of the appropriate working fluid and experimental studies on the expansion apparatuses (i.e. volumetric and velocity type) .fig.1 illustrates classifying for the systems of electricity generation.

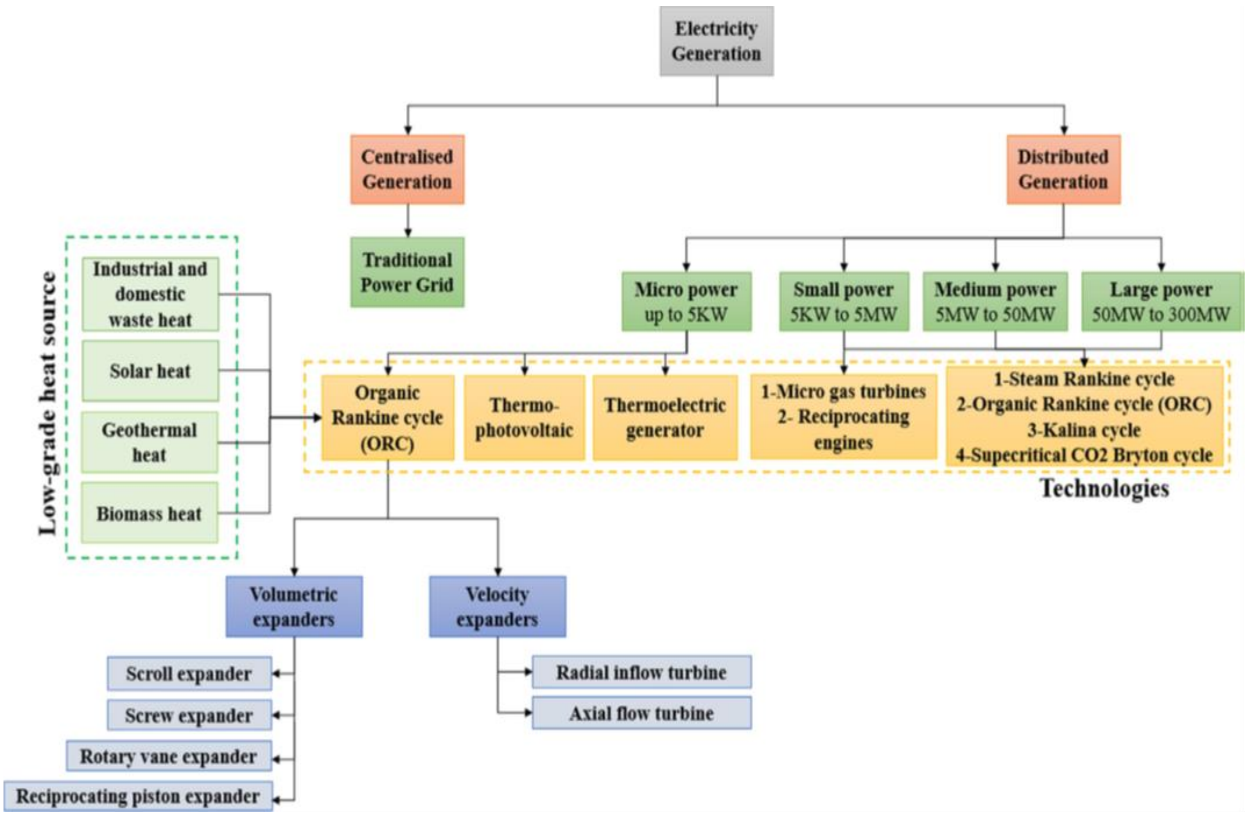

Figure 1: Classifying of technologies and electricity generation systems

2. ORC Background

Organic Rankine cycle (ORC) same as the steam Rankine cycle (SRC), but variance from it utilizing organic fluids instead of water such as(hydrocarbon, refrigerants, ethers and siloxanes) instead of water The temperature of heat sources range from (40-250)C. Ethers was used as a working fluid for the engine for the first time in 1826[9]. Efforts were made to develop technology (ORC) by exploiting solar and geothermal energy at the beginning of the twentieth century [10-13]. The diagram [2] shows the types of low heat sources used in (ORC) the application of biomass is the largest because they generate 1Mw for decentralized solid fuel applications. The application of solar energy ranked fourth by 1% due to lack of awareness of the use of solar radiation, but there are still ways and possibilities for growth [14]. The eighties of the last century has become (ORC) common in the market. More than 200 electric power projects totaling 2000 MW have been built [15].

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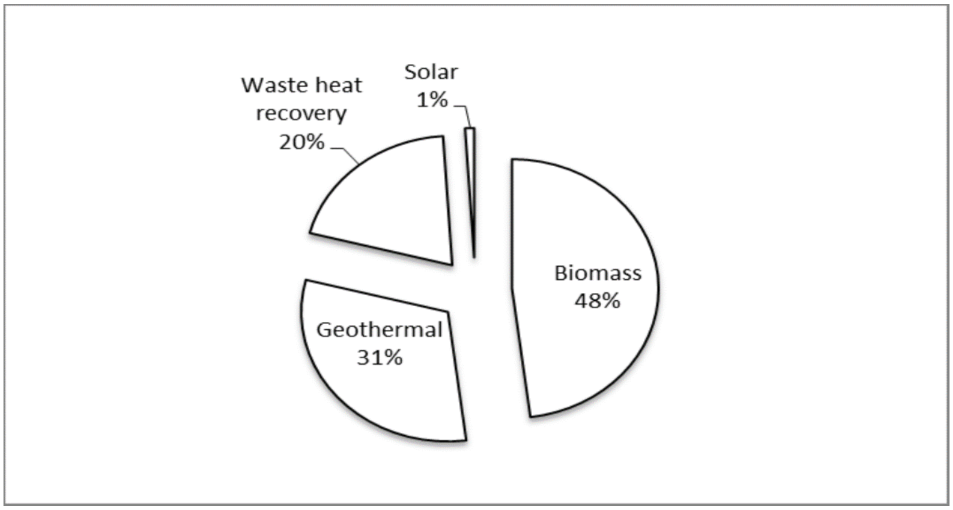

Figure 2: The ORC market for various sources of heat [16]

3. ORC Process

The cycle of (ORC) consists of the main parts such as the expander, evaporator, condenser and pump and does not need a steam vessel connecting with the boiler and contains one heat exchanger by three processes such as reheated, superheated and evaporation [17]. Figure.3 demonstrates schematic of the (ORC).

1-2: In this procedure, the process of pump the working fluid from the condenser into the evaporator and raising its pressure occurs.

2-3: Add heat to the evaporator to heat the working fluids before enter the expander.

3-4: The operating fluid enlarges into the expander and the mechanical energy is converted into electric.

4-1: In this procedure the process of condensing the working fluids vapor occurs before enter the cycle and pump is repeating again. Fig.4 illustrates the temperature-entropy diagram of the organic Rankine cycle. The case of high temperature outside of the expander we add recuperate (heat exchanger internally) between the expander and condenser to reheat Working liquid before entering the evaporator [18.19].

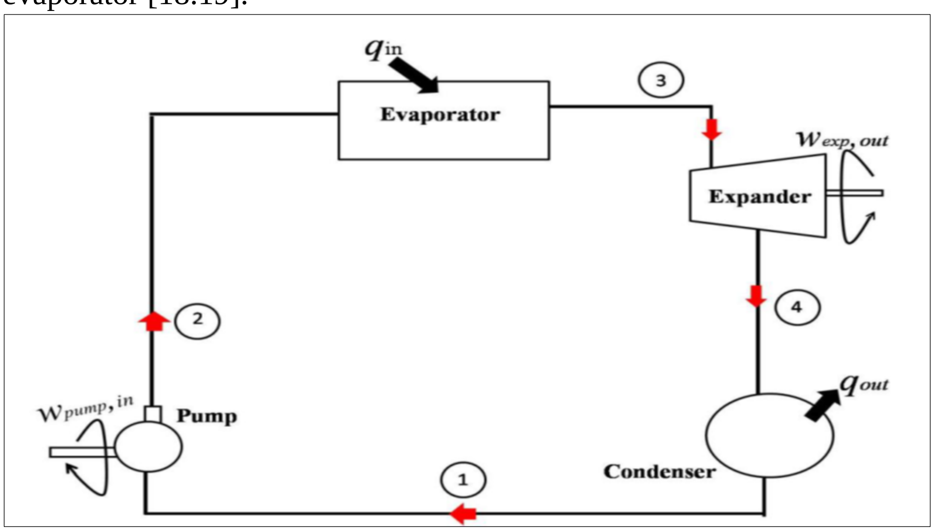

Figure 3: The ORC layout Schematic [18.19].

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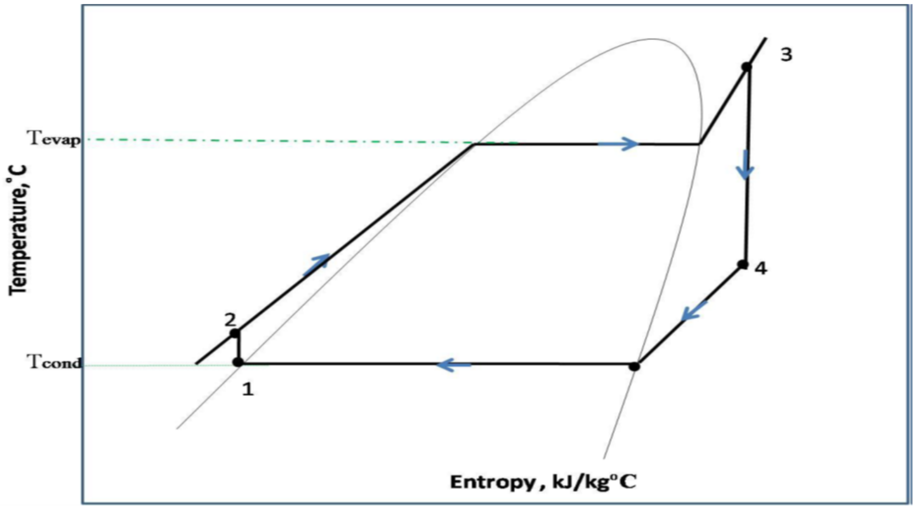

Figure 4: The diagram of entropy temperature of the simple ORC [18.19].

4. The Selection of Working Organic Fluid

The selecting of working fluid is an (ORC) significant factor. Physical- thermal working fluid characteristics that impact the system efficiency, volume of components, stability of the system, expander performance and the environment [20-22]. Organic work liquids are of high molar weight, low boiling point, and low boiling pressure. Working fluids are divided into 3 dry, isotropic and wet types with negative, zero and positive slope as presented in fig.5. Dry and isotropic fluids are more widely used and useful than wet because wet needs heating after expanded and re-heating equipment. There are thermal physical properties that are important in the selection of working fluids such as [23]

Latent Heat of Vaporization

The working fluids allows the heat to be transferred to the evaporator and reduces the irreversibility of the heat exchanger [22]. Therefore, the working fluids temperature of the evaporator is better than the heat source [24].

Specific Volume

The low specific volume of working fluids means low volumetric flow rate, small heat exchanger and also expander size, as well reduces cost fig.6 illustrates the vapor of exact volume of water and some organic fluids [23].

Critical Temperature

High temperature working mean good cycle efficiency [25].

Viscosity

Low viscosity of working fluids and steam reduces heat exchange and friction losses of pipes [23].

Environmental Impact

The working fluids must have zero possibility for loss of ozone, and moderate possibility for global warming.

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Thermal Stability

There is a possibility of decomposition of organic working fluids under high both pressure and temperature situations, which leads to ignition and corrosion, so it is essential to keep a thermal steadiness [23].

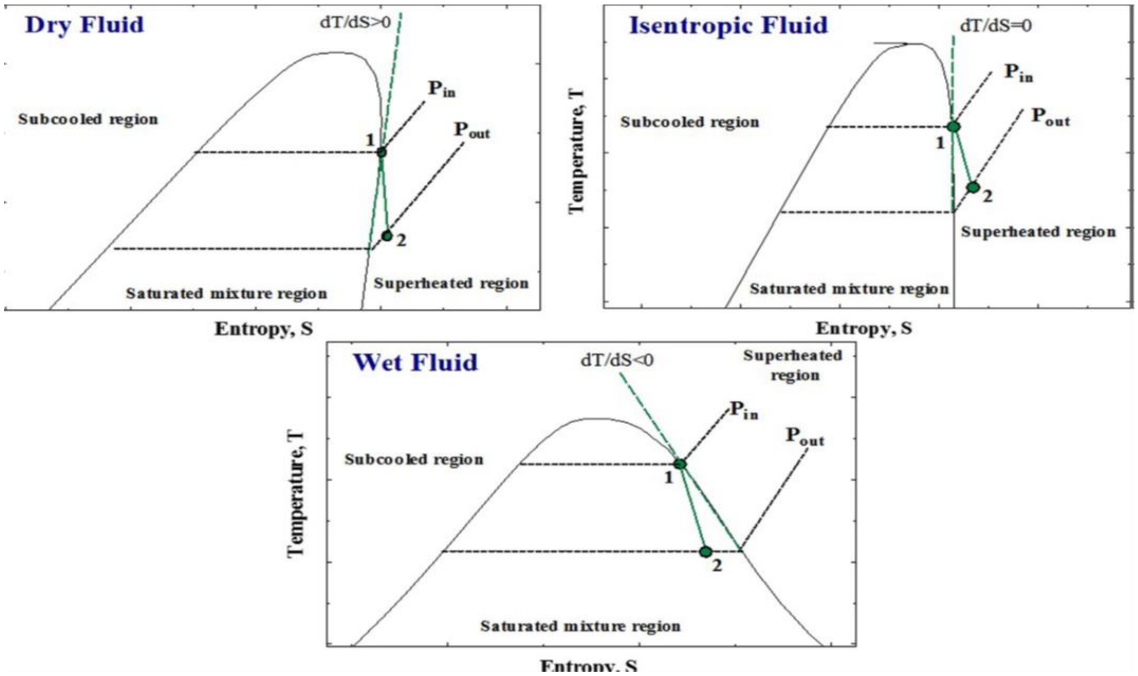

Figure 5: The diagram of entropy temperature of wet fluids, isentropic and dry [23].

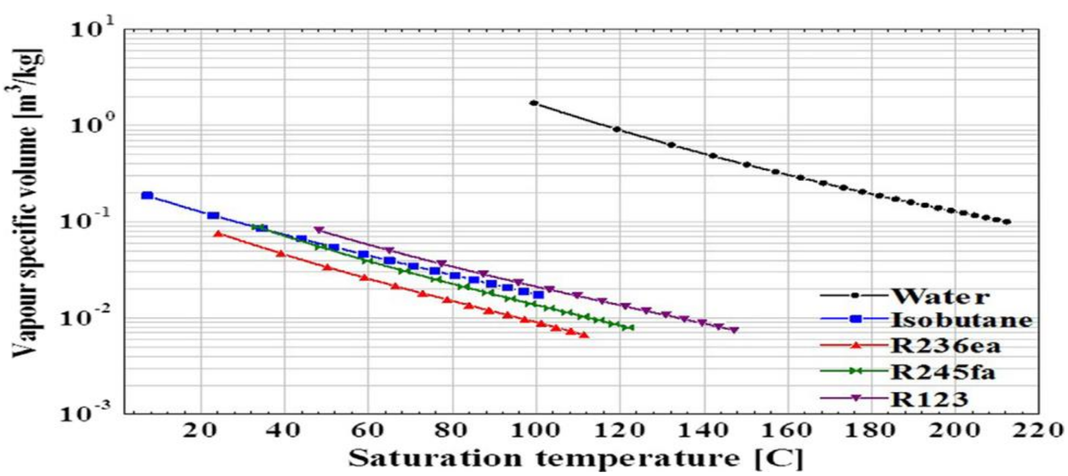

Figure 6: The temperature of saturated vs. saturated vapor specific volume for some public refrigerants in addition to water [23].

5. Comparison of (ORC) with (SRC)

Compared between (SRC) and (ORC) cycle is one of the significant ways for converting thermal energy to the power. Used water as a working fluid. Water properties available, cheap, viscosity, low thermal stability and high heat quality and high latent heat. Non - flammable and corrosive and environmentally friendly. Considered a type of wet fluid with a negative slope as demonstrated

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in figure [7]. [26]. Due to the property of water needs high temperature superheated above 500C so you (SRC) need high temperatures to prevent the water droplets passage, causing dangers to the expander [27]. In the Rankine cycle temperatures are greater than 300C, which means that it does not require heating equipment and easy than unlike water the entropy variation is between the saturated liquid lines and the steam is greater than the rest of the organic fluids. The result high irreversibility in the evaporator in (SRC) and the efficiency of exergy small compared with (ORC) The water mass flow rate is very small and the pump power of consumption is less compared with the (ORC) [28].

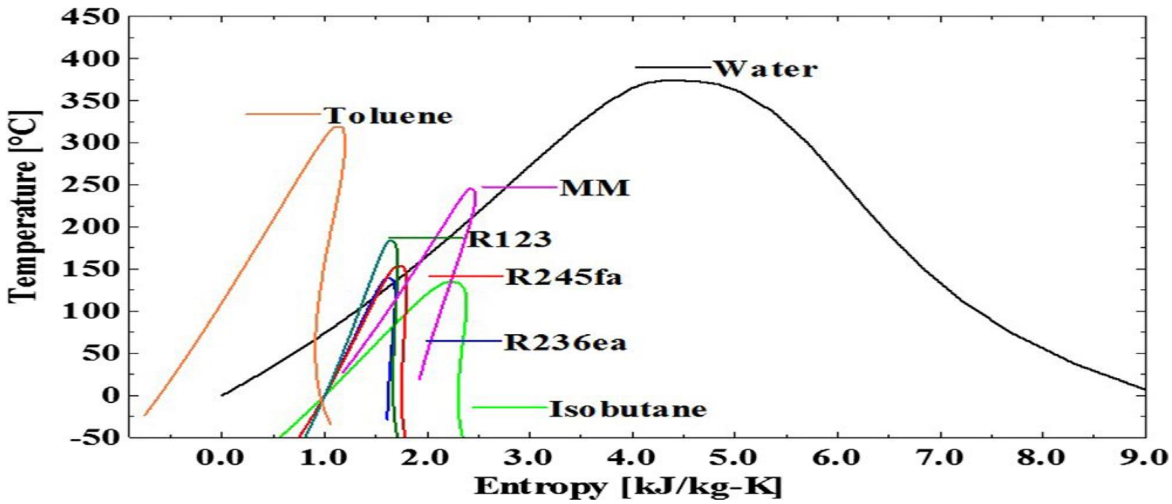

Figure 7: The diagram of entropy temperature of water and some public organic working Fluids [26].

6. Expansion Apparatus

The expansion apparatus of the major parts in (ORC) have a substantial function to calculate the (ORC) selection expander efficiency was important in the development (ORC) Their choice based on many factors like operation situations and the type of working fluid used. Expansion machines divided into two type volumetric type such as rotary vane expander, scroll, screw, reciprocating piston and velocity kind such as radial inflow and axial flow turbine [29].

6.1. Scrolling Expander

The expanders scrolling were classified into 3 kinds which are hermetic refrigeration compressor, automotive air condition compressor and open drive as displayed in fig. 8[30]. Air compressor coil spiral fused one fixed and the second rotates if the coil moving direction and synchronized with a fixed wrap less distance between them and if the direction of rotation, the distance increases fig .9 showed the scroll expander working principle [23]. An experimental investigation of the (ORC) with scroll expander. Used R-113 as a working fluid and solar collector parabola with the utilized of hot water heating medium and solar energy showed the results of scroll efficiency 63% and (ORC) efficiency 12%. In the case of the use of solar radiation, the (ORC) efficiency 11% and the efficiency of the scroll expander 65% [31]. Proposed a semi-experimental scroll expander model in (ORC). They used a working fluid R-123. Conclusion from the results there are problems of leak and little volumetric performance. They found Cycle efficiency 7.4% and scroll efficiency 68% [32].

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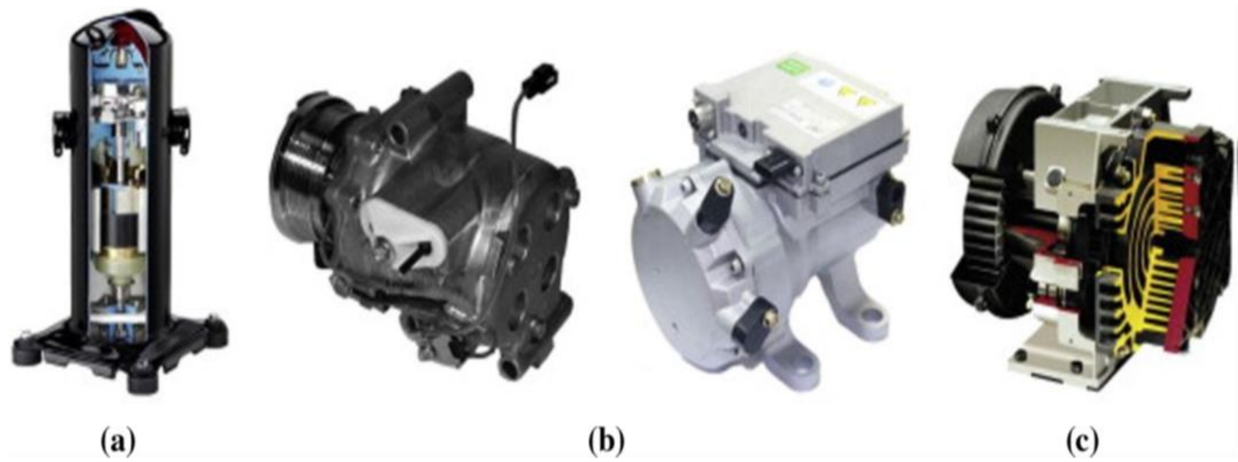

Figure 8: expander kinds, (a) hermetic refrigeration compressor, (b) automotive air-conditioning compressor, (c) open drive air compressor [30].

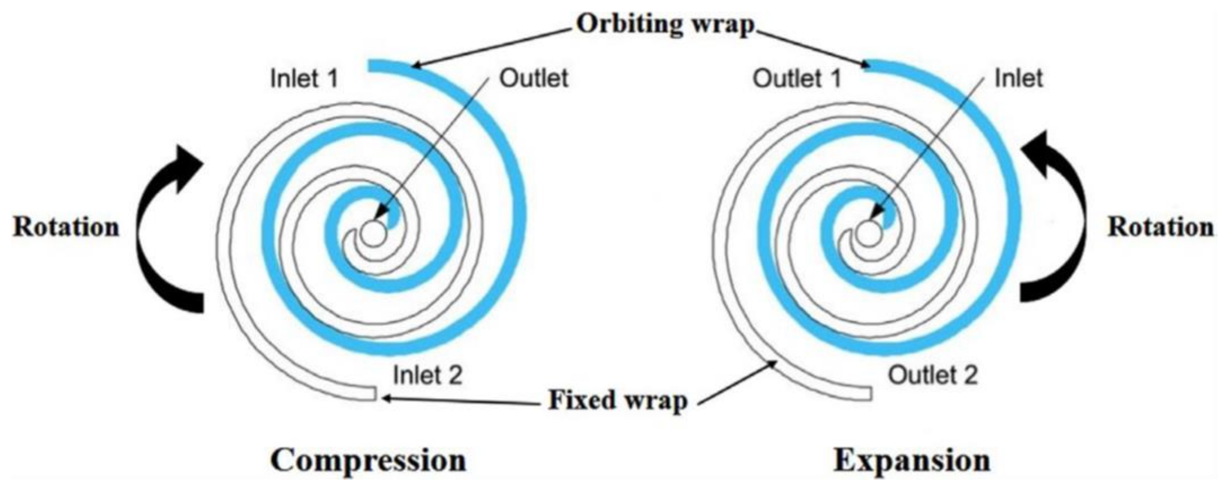

Figure 9: The principle of working for the expander and scroll compressor [23]

6.2. Screw Expander

The expansion apparatuses used in (ORC) plants, particularly in the applications of geothermal and waste [22]. Involves a pair of rotors female and male spiral meshing [29]. Expansion process occurs in three phases begin the entry of liquid into the spiral pair starts rotation and then the size of the spacing of the teeth starts to increase because of the pressure of the liquid. Finally when the size of the spacing of the tooth connected to the exit reaches the size of the spacing of the teeth to Zero exhaust [23]. Experimental investigation of the cost effectiveness of (ORC) with used of twin screw expander and working fluid R-124 as. The power range from (20-25) kWe. Results showed the total cost range from (1500-2000) $ depends on size [33]. Used single screw expander under several operating cases as internal flow and humidity different. Torque and rotation speed steady. Utilized air as a working fluid. The outcomes show a total power 5(Kw) with -45 ° C as a temperature, inlet pressure 600Kpa. Concluded that the screw part was well done and the efficiency ranges from (20%-30%). Be few due to leak or lubrication problems [18, 19].

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Figure 10: Working general design and principle of a screw [40]

6.3. Reciprocating Piston Expander

Reciprocating piston expander is one of the difficult apparatuses which need accurate exhaust and inlet valves, as a result of large moving parts there are very large friction losses. It used more commonly in internal combustion engines (ICE) with the (ORC) [23]. Proposed a semi-experimental model of the piston expander taking into account mechanical, ambient and internal losses. The outcomes illustrate the expander efficiency 70% and volumetric efficiency 60% [34]. Worked design piston with (ORC). Used Working fluids R245fa and n-pentane. Notice from the results the highest efficiency of the expander doesn't exceed 65 percent because of the low shaft speed for high displacement [35].

6.4. Expander of Rotary Vane

Rotary vanes expander are essentially an air motor that uses compressed air to move the motor [29]. The air motor converts compressed air into mechanical energy. They can work in the opposite direction to be as expander. If the spaces of chamber between the wall of cylinder and the increasing of vanes and the rotor rotates clockwise with the cylinder in this case expansion process occurs. Begin the organic working fluids to the vanes from the chamber (A). The trapped steam expanded and the volume of the chamber increases until the vanes passes outlet port [29].Experimental biomass-fired with (ORC) and rotary vanes expander. They used working fluids as HFE7000 and HFE7100. They found total electrical efficiency 1.41%, maximum expander efficiency 55.45% and net power 1W [36].

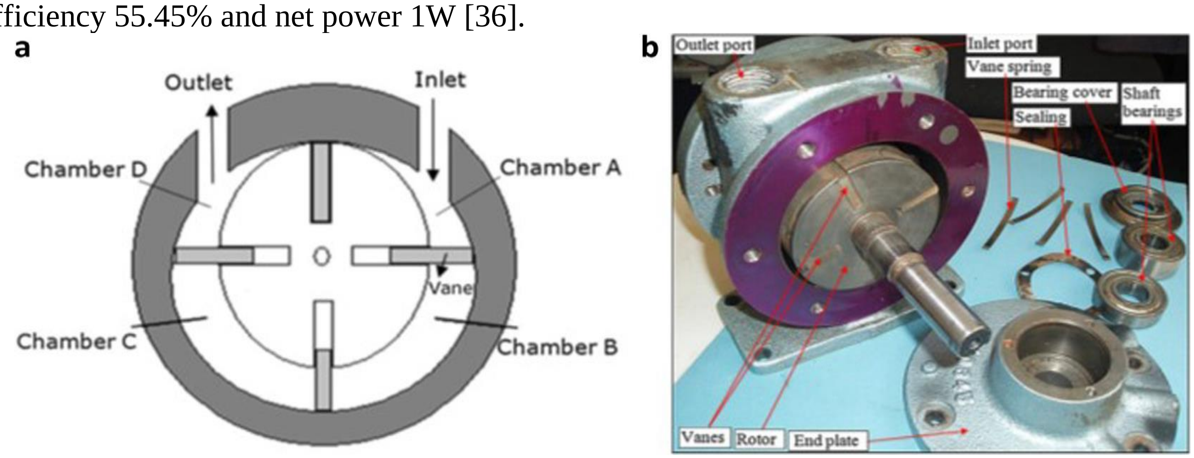

Figure 11: Working principle of rotary vane expand [29].

6.5. Turbo – Expander (Radial and Axial Turbine)

Turbines were mechanical apparatuses, which converting kinetic energy to mechanical energy of the shaft by dynamic blade movement. Turbines are divided into two type axial and radial flow based on path flow. Radial turbines need few equipment and few phases so they cost less than aide country turbine is suitable for Rankin with low flow rate, high compression ratio and high power outside compared with axial turbine suitable for high capacity cycles greater than 250, high flow rate and high expansion ratios [37]. Designed (ORC) with the use of a working fluid R245fa and radial turbine. The results indicated by modeling the highest turbine efficiency at 75% at the temperature of the turbine entry 80 °C and the entry pressure 7.32 bar. The outcomes of experiment of (ORC) design show a maximum cycle efficiency of 5. 55 and a maximum power of 32. 7kWe [38]. Proposed initial design of the radial turbine for the (ORC). Used three working fluids (R245fa, iso- pentane, isobutene). Found through the results maximum power 26. 3kWe and isotropic efficiency 77% with 30.2 bar as an inlet pressure and a temperature 180° C [39].

Table 1: Experimental investigations of ORC with use expander Summary

References	**Expander kind**	**Operating cases and working fluid**	**Gained performance**
Zanelli, et al. [41]	Scrolling	R134a, ω= 2400–3600 rpm; ER=2.4–4; T_{eva}=170 ºC; P_{eva}=6.4 bar	η_{exp} = 65% ; $Power_{mech}$=1–3.5 kW
Kane, et al. [42]	Scrolling	R123, R134a; ω= 3000 rpm; ER = 2.3; T_{eva} = 120–150 ºC	η_{exp} = 68%; $Power_E$=7.32 kW_E; $\eta_{cyc, th}$ = 13.67%
Peterson, et al. [43]	Scrolling	R123; ω=1400 rpm; ER=4.57; T_{eva}=174 ºC; P_{eva}=6.4 bar	η_{exp} = 49.9%; $Power_{mech}$=0.256 kW; $g_{cyc,th}$=7.2%
Saitoh, et al. [44]	Scrolling	R113; ω =1800 rpm; T_{eva} =136º C; P_{eva}=9.4 bar	η_{exp}=63%; $Power_{mech}$=0.45 kW; $\eta_{cyc,th}$=12%
Mathias, et al. [45]	Scrolling	R123; ER=3–8.3	η_{exp}=48.3% ; $Power_E$=2.9 kW_E
Lemort, et al. [46]	Scrolling	R123; ω=2660 rpm; ER=5.2; T_{eva}=143 ºC; P_{eva}=10 bar	η_{exp} = 68%; $Power_{mech}$=1.8 kW
Wang, et al. [47]	Scrolling	R134a; ω=3670 rpm; ER = 2.65–4.84; P_{eva} = 8–9 bar	η_{exp} = 77%; $Power_{mech}$=0.8 kW
Lemort, et al. [48]	Scrolling	R245fa; ω = 2660 rpm; ER = 5.7; T_{eva} = 140 ºC; P_{eva} = 6–16 bar	η_{exp} = 68%; $Power_{mech}$=2.2 kW

7. Conclusions

This paper provides complete the (ORC) review such as expansion apparatuses, the selecting of Working fluids and cycle configurations. Most studies that have been conducted on the (ORC)

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include selecting appropriate working fluid for different uses, thermodynamic Modeling and improving (ORC). Other less studies conducted Expander design, modeling and experimental study. Experiment research included an expander and most of them used volumetric type a special (scroll) has been updated and modified to be considered a compressor apparatuses and is not dedicated to the selecting of working fluid. Review on the characteristics of working fluids used in the (ORC). Few researches on experimental testing of the turbo-Expander have been used single stage with an expansion ratio of 5 but require high efficiency with a high expansion ratio so used multi stage expander.

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