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Parametric Analysis of Various Working Fluids for Solar Pond Electricity Generation

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***ABSTRACT*-Solar-thermal power plants have enjoyed limited success in the energy market till date. The ability to better characterize the performance of existing solar-thermal technologies as well as investigate the potential of new technologies is a crucial step in developing more economically viable designs. Organic Rankine cycle is primarily used to generate power from low temperature applications. . Organic Rankine cycle similar to conventional Rankine cycle the only change is that instead of water as working fluid, organics fluids like refrigerates and azeotropes are used. ORC proves to be a good option for a small and medium sized plant, generally of less than 10 KW**

The objective of this report is to evaluate the various working fluids to extract the energy from a low grade and low temperature heat sources like solar power, geothermal and waste heat recovery. Organic Rankine cycles have unique properties that are well suited to solar power generation. The thermodynamic potential of a variety Organic Rankine cycle working fluids and configurations are analyzed. To check for appropriate working fluid various working fluids have been analyzed like R-236fa,R-236ea,R-245ca and toluene

The parametric study of various working fluids on excel sheet for turbine inlet pressure is being done along with it, efficiency calculation based on recuperation and no recuperation is being done and the graphs are plotted as the result of the study

INTRODUCTION

The global demand for energy continues to increase while traditional energy resources are becoming scarcer. Exacerbating the situation is growing realization that the use of traditional fuels carries a significant environmental burden. Adoption of environmentally benign and renewable energy conversion technologies is essential if our society is to retain its advanced lifestyle in the face of global development

Economic opportunity drives the energy market just as it drives every market

Maximizing the economic opportunity associated with safe and renewable energy technologies is an essential step towards increasing their use. Taxes, penalties, incentives, public awareness and government mandates can all influence the economic opportunity associated with renewable energy technology. The principle focus of this thesis, however, is improving economic opportunity by providing tools for the evaluation and optimization of several specific renewable technologies: organic Rankine power cycles and thermal energy storage

Parabolic trough solar-thermal power generation is a proven technology. With several utility scale plants in operation for nearly 20 years. Current large-scale systems rely on traditional steam based Rankine cycles for power production. Organic Rankine cycle per plant are more compact and less costly than traditional steam cycle power plants and are able to better exploit lower temperature thermal resources. Utilizing organic Rankine cycles allows solar-thermal power generation to become a more modular versatile means of supplanting traditional fuels. While they have great potential, organic Rankine cycles have received relatively little attention

ORGANIC RANKINE CYCLE

Organic Rankine cycles are analogous to traditional steam Rankine cycles with an organic fluid as the working fluid in place of water. Many different organic fluids have been proposed and utilized as ORC working fluids, and fluids of particular interest for solar power applications .The following is a brief list of fluids that have been used or proposed for use in Rankine cycles: Toluene, Xylene, n-butane, R-11, R-22, R-248

The component processes that occur between the state points labeled as shown in fig are as follows:

1-2 The working fluid is expanded through a turbine

2-3 The turbine exhaust is used to preheat the working fluid exiting the pump

3-4 The working fluid is condensed

4-5 The working fluid is pumped from to high pressure

5-6 The working fluid is heated by turbine exhaust

6-1 Heat is added to the working fluid

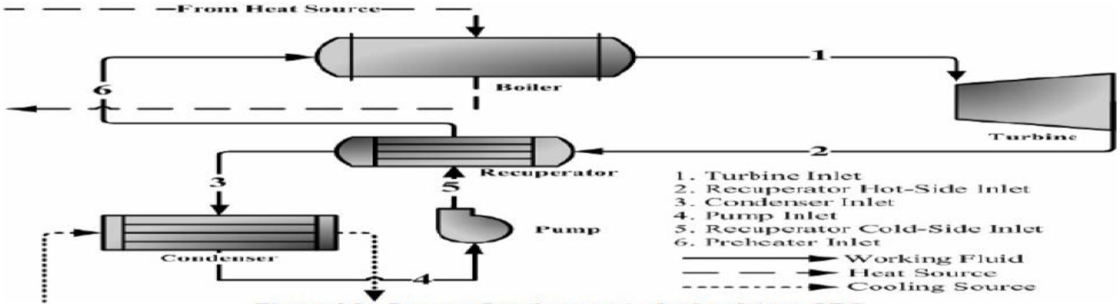

Figure 2.1: Process flow for a typical solar driven ORC

Figure 2.2 shows the general shape of a T-s diagram corresponding to the typical ORC configuration just described.

SOLAR POND

They are large shallow bodies of water that are arrange so that the temperature gradient are reversed from the normal. This allows the use for collection and storage of solar energy which may, under ideal conditions, be delivered at temperature 40-50 C above normal

ZONE OF SOLAR POND

1. UCZ (Upper Convecting Zone) : Top layer

1. This is a zone, typically .3m thick, of almost low salinity which is almost close to ambient temperature

2. UCZ is the result of evaporation, wind induced mixing, and surface flushing

3. Usually this layer is kept as thin as possible by use of wave suppressing mesh or by placing wind breaks near the ponds

2. NCZ (Non Convecting Zone) : Middle layer

1. In this zone both salinity and temperature increases with depth

2. The vertical salt gradient in the NCZ inhibits convection and thus gives insulation effect

3LCZ (Lower Convecting Zone) : Top layer

1. This is a zone of almost constant, relatively high salinity (typically 20% by weight) at high temperature.

2. Heat is stored in the LCZ, which should be sized to supply energy continuously throughout the year

ORGANIC RANKINE MODEL

The model is designed to compare and evaluates the potential organic Rankine cycle configuration

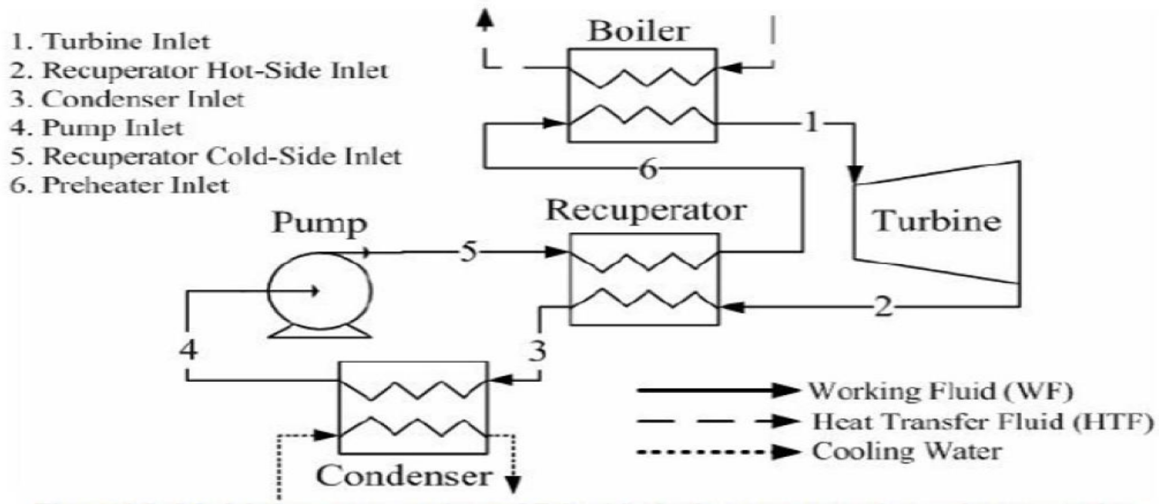

Figure 3.1: Modeled components in an ORC with single-stage expansion and recuperation

THERMODYNAMIC ANALYSIS AND PARAMETRIC STUDY

In research work, thermodynamic analysis of various working fluids like toluene, R-236fa, R236ea, R-245fa and R-134a is done. A parametric study was carried out to obtain the cycle efficiency of ORC along various saturation pressures. This is done to find the effect of turbine inlet pressure on the efficiency of the cycle

4.2 Thermo-physical Properties of various working fluids

Parameters	Toluene	R-236fa	R-236ea	R-245Ca
Chemical Formula	C_7H_8 or $C_6H_5CH_3$	CF3CH2CF3	C3H2F6	C3H3 F5
Molecular weight (g/mol)	92.1381	152.04	152.0383	134.05
Slope of saturated vapor line	Negative	Almost Isentropic	Negative	Negative
Critical temperature (°C)	318.6	124.92	139.29	174.42
Critical Pressure (MPa)	4.1263	3.2	3.50198	3.925
Boiling point at 1 atm (°C)	110.6	-1.44	6.19	25.13

CALCULATIONS FOR DIFFERENT WORKING FLUIDS

Parameters	**Toluene**	**R-236fa**	**R-236ea**	**R-245ca**
Assumptions of the cycle				
1.Turbine inlet temperature	70^0 C	70^0 C	70^0 C	70^0 C
2.Turbine inlet pressure				
3.Condenser saturation temperature	0.074246 Mpa	1.9396 Mpa	1.5720Mpa	.92819Mpa
4.Condenser saturation pressure	40^0 C	40 ^{0} C	40 ^{0} C	40^0 C
5.Carnot efficiency				
=(T_{boiler}-$T_{condenser}$)/T_{boiler}	0.0078923 Mpa	0.4377 Mpa	0.33765 Mpa	0.17347 Mpa
	42.857%	42.857%	42.857%	42.857%
Turbine and Generator Calculation				
1.$W_{Turbine}$				
=$W_{Electric}$/generator efficiency(.85)	1176.47 KW	1176.47 KW	1176.47 KW	1176.47 KW
2.inlet condition				
h 1=				
S1=	638.95 KJ/Kg	291.87 KJ/Kg	460.08 KJ/Kg	365.45 KJ/Kg
3. turbine efficiency	1.8661KJ/Kg	0.89125KJ/Kg	1.7481KJ/Kg	1.0988KJ/Kg
=(h_1-h_{2a})/(h_1-h_2)				
Therefore h_{2a}				
4.Turbine work per kg of working fluid	575.599KJ/Kg	270.331KJ/Kg	437.0535KJ/Kg	335.736KJ/Kg
=h_1-h_{2a}				
5. turbine work =(M_{wf}*W_t)	63.3505 KJ/Kg	21.539 KJ/Kg	23.0265KJ/Kg	29.93KJ/Kg
Therefore M_{wf}=				
	18.570kg/sec	54.620kg/sec	51.092kg/sec	39.307kg/sec
Calculation of Condenser				
$Q_{rejected}$=M_{wf}(h_2-h_3)	8267.169 KW	9469.9609 KW	9560.09KW	9162.12KW
We also know that				
$Q_{rejected}$=M_{of} C_p($T_{exhaust}$-T_{inlet})				
Therefore M_{of}	197.44 Kg/sec	226.175 Kg/sec	226.35 Kg/sec	216.82Kg/sec
Calculation of pump				
V_{f3}=	.0011752	.000746	.00072723	.00074201
P_5=	.074246	1.9396	1.572	.92619
P_4=	.0076923	.43777	.55765	.177347
1.W_p=V_{f3}(p_5-p_4)	.07797 KJ/kg	1.1405 KJ/kg	.89765 KJ/kg	.56001KJ/kg
We also know that				
W_p=(h_3-h_4)				
2.Therefore h_g=	130.48797KJ/Kg	98.1005 KJ/Kg	250.817 KJ/Kg	103.026 KJ/Kg
3.Pump efficiency				
=(h_g-h_4)/(h_{ba}-h_4)				
Therefore				
H_{ba}=h_4+(W_p/pump efficiency)	130.529 KJ/kg	98.7192 KJ/kg	251.202 KJ/kg	103.322 KJ/kg
Recuperator Design				
Effectiveness				
e=(h_2-h_3)/(h_2-$h_{3,min}$)				
e=	0.85	0.85	0.85	0.85
$h_{3,min}$=	534.41KJ/Kg	233.65KJ/Kg	397.2KJ/Kg	295.15KJ/Kg
therefore				
h_3=(e*(h_2-$h_{3,min}$))	542.8895KJ/Kg	239.184KJ/Kg	403.17KJ/Kg	301.237KJ/Kg
$Q_{recuperator}$=M_{wf}(h_2-h_3)=M_{wf}(h_6-h_8)				
Therefore h_6=				
	164.439 KJ/Kg	129.9592 KJ/Kg	283.8035 KJ/Kg	135.790 KJ/Kg
Calculation of Boiler				
Q_{boiler}=M_{wf}(h_2-h_6)	8983.20811 KW	8843.567KW	9005.966KW	9028.15KW
Efficiency of cycle				
=($W_{turbine}$-w_{pump})/Q_{boiler}	13.0802%	12.462%	12.554%	12.787%

Table 4.2 Parametric Study for Toluene

Turbine Inlet Pressure	Turbine Work/ Working Fluid	Mass Flow Rate of The Working Fluid	Condenser Heat Rejected	Mass Flow Rate of Cooling Fluid	Pump Work	Heat Addition in Boiler	Efficiency	Heat rejection With Recuperation	Heat Addition with Recuperation	Efficiency with Recuperation
0.056246	55.4285	21.225	9634.909	230.1149	0.05701	10809.65	10.882988	8786.902321	9961.643569	11.8094266
0.058246	56.457	20.83834	9436.078	225.3661	0.05937	10610.78	11.086937	8622.166232	9796.868772	12.0080268
0.060246	57.2815	20.53839	9281.475	221.6736	0.06173	10456.13	11.250892	8494.303791	9668.96258	12.16685099
0.062246	57.46	20.47459	9246.94	220.8488	0.06409	10421.53	11.288221	8466.775726	9641.371166	12.20164529
0.064246	58.1485	20.23216	9121.702	217.8577	0.06645	10296.25	11.425552	8363.375785	9537.925261	12.3339565
0.066246	59.007	19.9378	8970.078	214.2364	0.06881	10144.59	11.596343	8237.913815	9412.424066	12.4983871
0.068246	60.2905	19.51336	8752.316	209.0355	0.07116	9926.802	11.850733	8057.17989	9231.666123	12.74308257
0.070246	60.8005	19.34968	8667.097	207.0002	0.07352	9841.535	11.953384	7987.234888	9161.672575	12.84041171
0.072246	61.4635	19.14095	8559.193	204.4231	0.07588	9733.588	12.085924	7898.194838	9072.589964	12.96646409
0.074246	62.1435	18.93151	8450.958	201.838	0.07824	9625.312	12.221856	7808.854057	8983.208109	13.09545262

Table 4.3 Parametric Study for R 236fa

Turbine Inlet Pressure	Turbine Work/ Working Fluid	Mass Flow Rate of Working Fluid	Condenser Heat Rejection	Mass Flow Rate of Cooling Fluid	Pump Work	Heat Addition in Boiler	Efficiency	Heat Rejection with Recuperation	Heat Addition with Recuperation	Efficiency with Recuperation
1.7596	20.1875	58.27715	10371.031	247.696	1.010909	11442.36	9.7668409	8344.902038	9416.230969	11.86841208
1.7796	20.587	57.14626	10129.803	241.9346	1.026205	11201.92	9.9788778	8176.969387	9249.089934	12.08579706
1.7996	20.6975	56.84116	10051.82	240.0721	1.0415	11123.26	10.044451	8129.728853	9201.164473	12.14270119
1.8196	20.7315	56.74794	10015.813	239.2122	1.056796	11086.18	10.071087	8113.46777	9183.835657	12.15721888
1.8396	20.8845	56.33221	9915.7924	236.8233	1.072092	10985.71	10.159353	8050.031676	9119.94596	12.2377558
1.8596	20.978	56.08113	9848.4077	235.2139	1.087387	10917.57	10.217365	8010.673848	9079.837636	12.28533088
1.8796	21.0035	56.01305	9817.0984	234.4662	1.102683	10885.17	10.240589	7998.045346	9066.11548	12.29529211
1.8996	21.131	55.67507	9732.3928	232.4431	1.117978	10799.9	10.317007	7945.966124	9013.473772	12.36178748
1.9196	21.233	55.40762	9661.7038	230.7548	1.133274	10728.52	10.380533	7904.204536	8971.024918	12.4141667
1.9396	21.3265	55.1647	9595.9825	229.1852	1.14857	10662.08	10.439892	7866.046452	8932.142165	12.46184267

Table 4.4 Parametric study for R236ea

Turbine Inlet Pressure	Turbine Work/ Working Fluid	Mass Flow Rate of Working Fluid	Condenser Heat Rejection	Mass Flow Rate of Cooling Fluid	Pump Work	Heat Addition in Boiler	Efficiency	Heat Rejection with Recuperation	Heat Addition in Boiler with Recuperation	Efficiency with Recuperation
1.392	21.6665	54.299	10377.28	247.85	0.767	11494.3	9.87306	8354.17909	9471.17187	11.9820014
1.412	21.7175	54.172	10334.98	246.83	0.781	11451	9.90435	8331.87105	9447.87793	12.0042387
1.432	21.8025	53.96	10274.99	245.4	0.796	11390.1	9.95184	8296.43379	9411.55521	12.0439817
1.452	22.3125	52.727	9997.952	238.79	0.81	11113.4	10.2016	8100.47379	9215.9019	12.3020046
1.472	22.3975	52.527	9940.311	237.41	0.825	11054.9	10.2501	8066.77732	9181.34568	12.3417513
1.492	22.44	52.427	9904.053	236.54	0.839	11017.6	10.2786	8048.88451	9162.48078	12.3597355
1.512	22.508	52.269	9855.419	235.38	0.854	10968.1	10.3193	8021.7608	9134.46097	12.3907817
1.532	22.967	51.224	9619.577	229.75	0.869	10732.5	10.5472	7855.61244	8968.52273	12.6216795
1.552	22.7885	51.626	9688.654	231.4	0.883	10800	10.4711	7916.20378	9027.54353	12.5269828
1.572	23.0265	51.092	9561.025	228.35	0.898	10672	10.5942	7830.25943	8941.21077	12.6448975

Table 4.5 Parametric Study for R 245ca

Turbine Inlet Pressue	Turbine Work/ Working Fluid	Mass Flow Rate of Working Fluid	Condenser Heat Rejection	Mass Flow Rate of Cooling Fluid	Pump Work	Heat Addition in Boiler	Efficiency	Heat Rejection With Recuperation	Heat Addition With Recuperation	Efficiency With Recuperation
0.74819	26.7835	43.9252	10528.71	251.462	0.4264	11676.4	10.072	8876.896287	10024.54813	11.73163655
0.76819	27.302	43.091	10291.33	245.793	0.4413	11438.5	10.2813	8700.827737	9848.043058	11.9417503
0.78819	27.5825	42.6528	10159.78	242.651	0.4561	11306.3	10.4014	8606.966229	9753.505246	12.05734597
0.80819	28.1435	41.8025	9918.762	236.894	0.471	11064.9	10.6282	8427.698766	9573.880017	12.283411
0.82819	28.22	41.6892	9874.094	235.827	0.4858	11019.4	10.6719	8401.296504	9546.608053	12.31834579
0.84819	28.662	41.0463	9688.905	231.404	0.5006	10833.8	10.8547	8265.155312	9410.010227	12.49700396
0.86819	28.8235	40.8163	9612.923	229.59	0.5155	10757	10.932	8214.506316	9358.606491	12.56548731
0.88819	29.138	40.3758	9481.529	226.452	0.5303	10625.1	11.0676	8120.315878	9263.843613	12.69386358
0.90819	29.58	39.7725	9307.556	222.297	0.5452	10450.7	11.2521	7992.518773	9135.630701	12.87185164
0.92819	29.954	39.2759	9162.122	218.823	0.56	10304.8	11.4113	7886.881438	9029.513157	13.02296115

CONCLUSION

Various working fluids were analyzed with varying turbine inlet pressure and various graphs were plotted to show the effect of turbine inlet pressure on various parameters

1. The fig 5.1 shows the plot for the efficiency of various working fluids at various turbine inlet pressure from the figure it can be said that the toluene reaches to the maximum efficiency but the effect of turbine pressure is more in case of toluene whereas the effect is much less on the rest of the fluids

2. Fig 5.2 shows the plot for mass flow rate of the various working fluids required for generation of nominal power 1MW.From the graph it is seen that the toluene requires the most minimal mass flow rate for the same R-236fa requires much more mass flow rate as compare to rest of fluids. Thus the toluene suits the most viable option according to mass flow rate

3. Fig 5.3 depicts the heat addition required in the boiler generation of the same turbine work under different turbine inlet pressure fig 5.3 toluene requires the less heat addition

4. From the above graphs, it is indicated that the toluene gives out to be the best option for a 1 MW solar operated power plant .The other important analysis done here is the effect of recuperate on the overall efficiency of the plant

5. Fig 5.4indicates the increase in the efficiency of the plant with use of recuperation for toluene

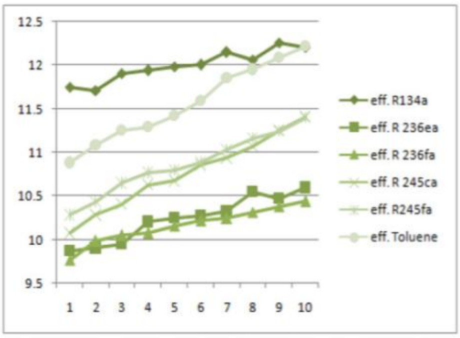

Figure 5.1: Efficiency of Various Working Fluid for Different TIP

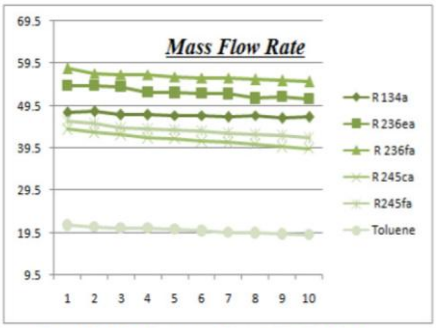

Figure 5.2 : Mass Flow rate of Various Working Fluid

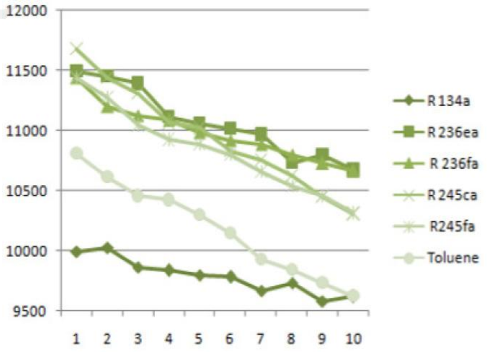

Figure 5.3: Heat Additionin the boiler for working fluids

Figure 5.4: Effect of Recuperation on Efficiency

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