American Journal of Mechanical Engineering, 2016, Vol. 4, No. 6, 215-217
Available online at http://pubs.sciepub.com/ajme/4/6/2

DOI:10.12691/ajme-4-6-2

Experimental Study of an Organic Rankine Cycle Unit Using Dichloromethane as Working Fluid

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Abstract The Rankine cycle (ORC) is an ideal and mathematical model which is mainly used to prognosticate the efficiency of steam engines. It's a thermodynamic cycle of a heat engine that converts heat into mechanical work. In Organic Rankine Cycle, organic substances are used rather than water as a working fluid. Organic working fluids are better than water because of having more turbine efficiency due to higher mass flow rate and low temperature heat source can be used to operate the cycle. In this research an experimental setup was locally fabricated to justify the usability of Dichloromethane as a working fluid of ORC power plant. The turbine of this set up was capable of driving a DC generator and it was able to produce up to 10 volts and .09A current while continuously operating the ORC. This preliminary concept was taken to further analyze the properties of Dichloromethane as a working fluid of ORC power plant at various load conditions. Dichloromethane was tested in a mini closed looped experimental nano power generation unit. Temperatures, pressures, mass flow rates, fuel consumptions, vapor generation rates, condensation rates etc. were measured. The nano unit runs at three different operating pressures of approximately 137. 206 and 275 Kpa. The unit had shown its best performance at the operating pressure of 40 psi using R-30 as a working fluid. Not only that, but for all operating pressure it was experimentally proven that, the overall efficiency of ORC unit is always higher than the overall efficiency of the same unit using water as a working fluid.

Keywords: *ORC, organic working fluid -dichloromethane, inorganic working fluid - water, impulse turbine*

Cite This Article: Md. Arafat Islam, Mir Sakib Mustashin, Ashfaq Ahmad Shoaib, Mohammad Asaduzzaman Asif, and Tahmidur Rahman, "Experimental Study of an Organic Rankine Cycle Unit Using Dichloromethane as Working Fluid." *American Journal of Mechanical Engineering*, vol. 4, no. 6 (2016): 215-217. doi: 10.12691/ajme-4-6-2.

1. Introduction

Many industrial processes produce waste heat that is typically rejected to lower temperature heat sinks. There are number of ways in which such waste heat can be recovered to produce useful energy. Recovery of waste heat offers the benefit of increasing overall efficiency in case of power generation or provides auxiliary power in other waste heat application. A standard Rankine cycle uses steam as a working fluid for primary power generation and it operates at relatively higher temperatures (523.15-873.15K) in order to maximize the Carnot efficiency. That's why low temperature heat sources are unsuitable for it. However Organic Rankine Cycle (ORC), which uses organic fluids rather than water and can operate at low temperatures to utilize the waste heat sources. It is the specialty of the organic fluids which can evaporate at low temperature and exert high pressure as compared to steam. That's why organic fluids make the cycle more efficient. But the main challenge is to condense the organic fluids. Here in this experiment dichloromethane was used as an organic fluid. The aim was to investigate ORC plant operating character compared to conventional steam turbine power plant.

2. Experimental Setup

2.1. Model A

An experimental setup was locally fabricated to justify the feasibility of Dichloromethane as a working fluid of ORC power plant. The turbine of this set up was capable of driving a DC generator and it was able to produce maximum 10 volts and .09A current while continuously operating the ORC. The plant was consisting of boiler, burner, turbine, DC generator and condenser. Figure 1 demonstrates the experimental set up of locally fabricated ORC plant.

Figure 1. Experimental setup of Model A

2.2. Model B

The P7669T is a miniature steam turbine power plant consists of furnace, boiler, micro steam turbine, condenser, fluid storage tank and a control panel. It is a total closed loop system. Control panel consists of different measuring instruments like ammeter, voltmeter, vortex shading meters, temperature meter, pressure meter and load switch. The plant consists of total four bulbs as loads. The maximum load of each bulb is 0.8 watt. Therefore the total plant capacity is 3.2 W.

Figure 2. Experimental setup of Model B

3. Experimental Results

Table 1. Turbine inlet temperatures at different pressures

Operating Pressure (KPa)	Turbine Inlet Temperature Steam Turbine Power Plant (K)Fluid H2O	Turbine Inlet Temperature ORC Power Plant (K)Fluid CH2Cl2
206	384.15	327.15
275	393.15	341.15

Table 2. Turbine exhaust temperatures at different pressures

Operating Pressure 206KPa				
For H_2O				
Parameters	Load Conditions			
	Load 1	Load 2	Load 3	Load 4
Dynamometer Voltage (Volts)	6	4	2.5	1.5
Dynamometer Current (Amps)	0.03	0.06	0.07	0.085
Power (W)	0.18	0.24	0.175	0.1275
Generator Speed (rad/s)	363	224	175	140
For CH_2Cl_2				
Parameters	Load Conditions			
	Load 1	Load 2	Load 3	Load 4
Dynamometer Voltage (Volts)	6.5	4	3	1.5
Dynamometer Current (Amps)	0.03	0.06	0.08	0.09
Power (W)	0.195	0.24	0.18	0.135
Generator Speed (rad/s)	371	234	187	142
Operating Pressure 275KPa				
For H_2O				
Parameters	Load Conditions			
	Load 1	Load 2	Load 3	Load 4
Dynamometer Voltage (Volts)	12	10	9	6
Dynamometer Current (Amps)	0.06	0.11	0.14	0.15
Power (W)	0.72	1.1	1.26	0.9
Generator Speed (rad/s)	911	735	545	361
For CH_2Cl_2				
Parameters	Load Conditions			
	Load 1	Load 2	Load 3	Load 4
Dynamometer Voltage (Volts)	12	11	9	7
Dynamometer Current (Amps)	0.06	0.11	0.14	0.17
Power (W)	0.72	1.21	1.26	1.19
Generator Speed (rad/s)	915	754	586	380

4. Results and Discussion

Figure 3 and Figure 4 represents the performance curves of steam turbine and ORC power plant respectively running at an operating pressure of 206 KPa. The plant was running with four different operating loads. Voltage, current, power and speed of the generator were measured to analyze the performance of the plant. As the load is increasing the voltage decreases. The electrical power output of the plant increases up to second load after that it is decreasing. It is because of the turbine speed is decreasing with the increasing of the load. It is true for both of the cycles. So this is the optimum operating zone when both of the plants are running at an operating pressure of 206 KPa. The plant operating performances are quite similar for the both plant running at a pressure 206 KPa. But even though there are some slight variations in generation of voltage and current. At load no 4 the power output is higher for ORC plant. Because the mass flow rate of dichloromethane vapor is higher than water. But this is not that much significant. The power output is also higher.

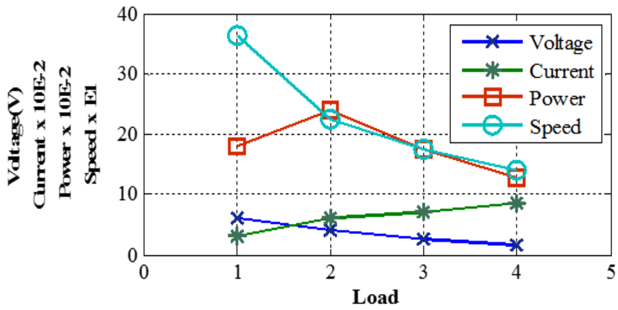

Figure 3. Performance curves of steam turbine power plant operating at 206 KPa pressure and different load conditions

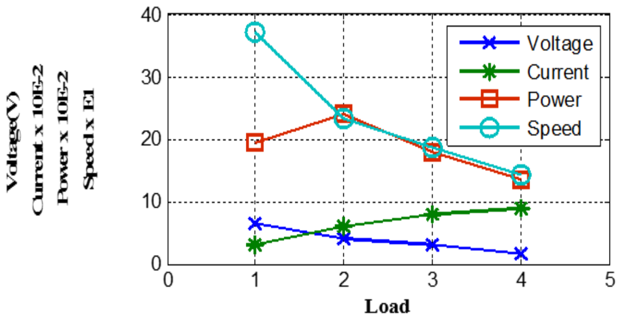

Figure 4. Performance curves of ORC plant operating at 206 KPa pressure and different load conditions

Figure 5 and Figure 6 represents the performance curves of steam turbine and ORC power plant respectively running at an operating pressure of 275 KPa. Both plants operated at four different load conditions. Voltage, current, power and speed of the generator were measured to analyze the performance of the plant. As the load is increasing the voltage decreases. The electrical power output of the plant increases up to third load after that it is decreasing. It is because of the turbine rpm is decreasing with the increasing of the load. It is true for both cycles. So load no 3 is the optimum operating zone, when both plants are running at an operating pressure of 275 KPa. The operating performance characteristics are also similar for both plants running at this pressure. But even though there are variations in generation of voltage, current and power. At load no 2, 3 and 4 the power output is higher for ORC plant. Because the mass flow rate of dichloromethane vapor is higher than water which is much significant for this power plant. The speed of the turbine is also higher. The performance of the power plant running at 275 KPa pressure is better than the plant running at 206 KPafor both cycles. So the plant power output increases with the increase of operating pressure.

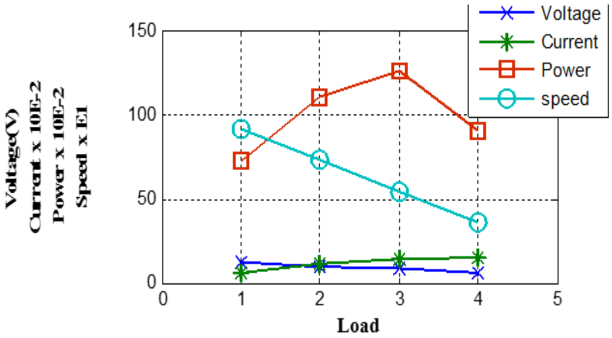

Figure 5. Performance curves of steam turbine power plant operating at 275 KPa pressure and different load conditions

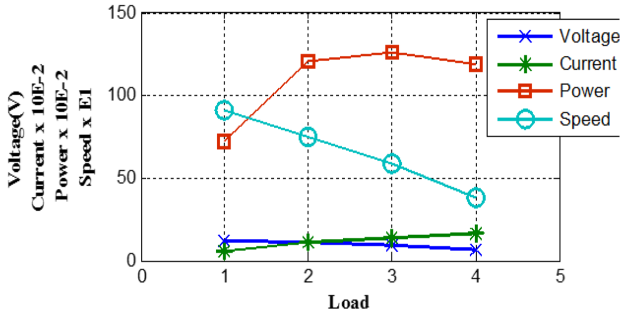

Figure 6. Performance curves of ORC plant operating at 206 KPa pressure and different load conditions

5. Conclusion

The overall efficiency of ORC power plant using dichloromethane as a working fluid is quite higher than the overall efficiency of the same unit. As the boiling temperature of the dichloromethane is higher compared to other ORC fluids but at the same time, relatively higher condensation temperature of dichloromethane minimize the energy input required for condensation.

Acknowledgement

The Authors would gratefully like to acknowledge the endless support by Military Institute of Science and Technology (MIST), Dhaka, Bangladesh for supporting this research-work by giving lab facilities.

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