

Experimental study of An Electrogasdynamic Ejector

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Abstract: Electrogasdynamic (EGD) power generator employs an electrically charged working fluid. When the electric charge is moved by the working fluid against an electrical force, the kinetic energy of the working fluid is converted to electricity. An EGD generator may be integrated into an ejector to form a combined heating, cooling and power generation system. The system may be driven by solar energy or waste heat. The experimental setup of an EGD ejector system is described in this paper and some experimental results are presented. The EGD output power is very limited for air, R134a, R123, and HFE7100 as the working fluid. The change in the nozzle outside size due to integrating an EGD generator has little effect on ejector performance.

KEYWORDS: electrogasdynamics(EGD), ejector

1. INTRODUCTION

Electrogasdynamics (EGD) power generator converts the kinetic energy of a charged working fluid directly into electricity. It is based on the movement of a charge within an electrical field. When a working fluid carries a charge toward a higher potential, it does work. As a result, the working fluid slows down and its kinetic energy is directly converted to electricity^[1]. An EGD generator includes three electrodes: a charge emitter, an attractor and a charge collector. An activation voltage is applied between the emitter and the attractor to charge the working fluid. The conversion of kinetic energy to electricity is carried out between the attractor and the collector. The collector has a higher potential than the attractor. Higher collector voltage leads to higher EGD output power, but this is limited by the dielectric strength of a working fluid. The EGD power generator has the feature of high voltage and low current^[2]. Use of a charged aerosol is important for efficient operation of an EGD ejector^[3]. A charged aerosol is comprised of a carrier gas and charged particles. A charged particle has a larger momentum to travel with its carrier gas than a single charge. This would prevent the charge from drifting to the grounded attractor by the electrical force. The aerosol may be formed by condensation and liquid injection.

The EGD generator has been used as a high voltage supply for the applications in paint spraying, crop spraying, coating and precipitation, where a compressed air is the working fluid^[1]. The EGD generator may be used to replace a turbine generator in a Rankine cycle. Compared with a turbine generator, there are no moving parts in an EGD generator and so it would be simple and compact. An EGD power generator may be incorporated with an ejector cooling system and the configuration of an ejector allows an easy integration of the EGD generator. This integration system would provide a novel approach for combined heating, cooling and power generation. This study will present the experimental investigation of an EGD ejector.

2. EXPERIMENTAL SETUP

The experimental EGD ejector system consists of an EGD ejector, a boiler, a condenser, an evaporator and a pump, as shown in Figure 1. The boiler, condenser and evaporator were plate-type heat exchangers. The boiler was heated by a hot water. The flow rate of liquid refrigerant from the condenser and to the evaporator was measured by two flow meters. A transparent tube was connected to each heat exchanger to indicate the liquid level. The pump was a gear pump for stable circulation of liquid, and its flow rate was controlled using a frequency inverter.

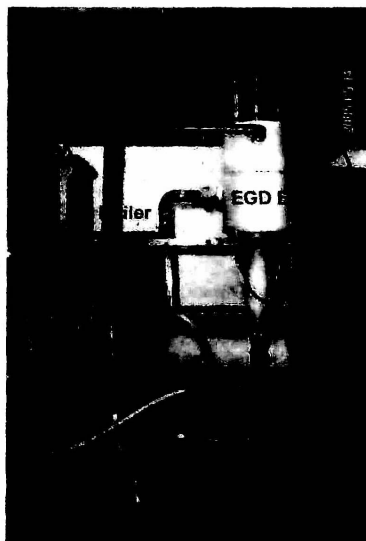


Figure1: EGD ejector system

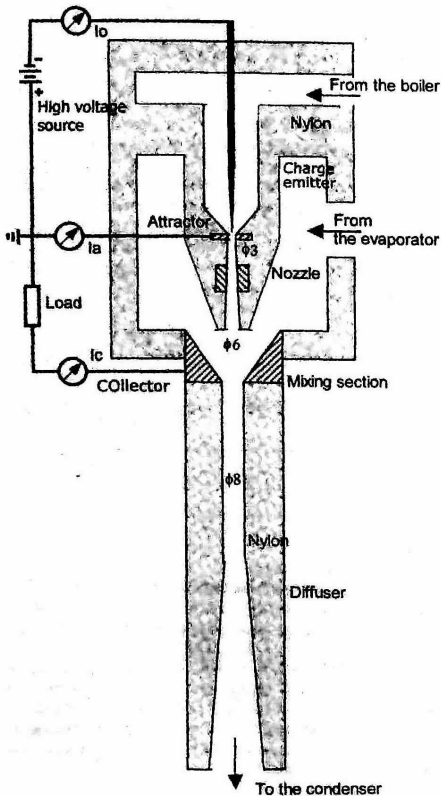


Figure 2: View of the EGD ejector

The EGD ejector is a combination of an ejector and an EGD power generator. Figure 2 is a schematic view of the EGD ejector. For the purpose of electrical insulation, the ejector was made of nylon. The ejector is comprised of a converging-diverging nozzle, a conic mixing section, a constant-area mixing section and a diverging diffuser. The gaseous working fluid was expanded to a supersonic flow through the nozzle. The vapour from the evaporator was entrained by the supersonic flow in the conic mixing section. They continued to mix in the constant area section and underwent a shock wave. The mixture was then pressurised in the diffuser. The nozzle throat was 3mm in diameter, the nozzle exit was 6mm and the constant-area mixing section was 8mm. The EGD power generator includes three electrodes: a

charge emitter, an attractor and a charge collector. The attractor was placed at the throat of the nozzle, and the charge emitter was positioned centrally in the entrance of the nozzle. The charge collector was placed in the nozzle and in the mixing section. An Alpha III high voltage supply was applied between the charge emitter and the grounded attractor. The charge emitter was a sharp needle, and the high electric field around the needle tip caused a corona charging effect, by which the working fluid was electrically charged. The high speed of the working fluid prevented most charge from drifting to the grounded attractor. After passing through the attractor, the working fluid pushed the charge to the collector, resulting in a high potential. When the charge was moved against the high potential by the working fluid, the kinetic energy of the working fluid was converted into electricity. A high voltage resistor of 1Gohms was connected to the collector as a load. The input, output and attractor current were measured using three 0-100uA micro-ammeters. The EGD output voltage and power were calculated from the load resistance and measured current.

3. RESULTS AND DISCUSSIONS

3.1 EGD conversion

The system was first tested for EGD conversion using a compressed air. The charge emitter current was set at 20uA, the load was 1Gohms and the collector current was measured at different nozzle inlet pressure. Figure 3 shows the results for two collector positions—in the nozzle and in the mixing section. The collector current was smaller for the former. This may be because the air velocity in the nozzle was very high so that the air would swept most charge off the collector. The air velocity at the mixing section was smaller, so the collector current was larger for the collector in the mixing section. It was easy to place the collector at the mixing section, so this collector position was used for the following experiments. Figure 4 gives the voltage and power for the collector in the mixing section. It can be seen that an output voltage of 11-12kV was achieved for an input voltage of 5-6kV. The output power was about 0.1W.

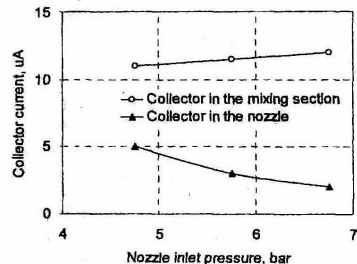


Figure 3: Collector current against pressure (air, 20uA input and 1Gohm load)

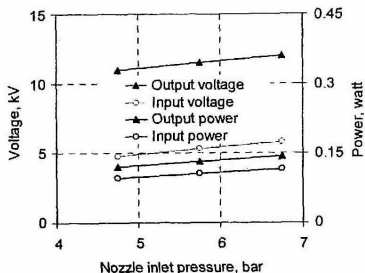


Figure 4: Collector voltage and power for the collector in the mixing section (air, 20uA input and 1Gohm load)

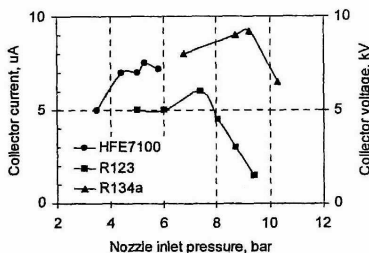


Figure 5: Collector current against pressure (20uA input and 1Gohm load)

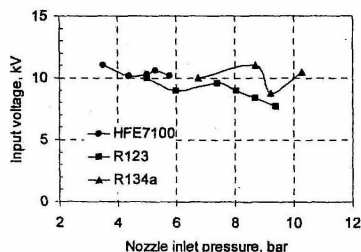


Figure 6: Input voltage against pressure (20uA input and 1Gohm load)

Figure 5 gives the collector current for three refrigerants: R134a, R123 and HFE7100. Their physical properties are given in Table 1. It can be seen that the collector current for these refrigerants is smaller than air. The reason may be that their speed in the nozzle was smaller and so the momentum of the charge was insufficient to prevent itself from drifting to the grounded attractor by the electrical field.

Their input voltage as shown in Figure 6 was higher than air. These refrigerants have larger dielectric strength than air by 2-3 times, so they were charged at a higher voltage between the charge emitter and attractor. Along with their smaller velocity in the nozzle, this higher voltage caused more charge to drift to the attractor, resulting in a less collector current. The output voltage was even less than the input voltage. The EGD output power was around 0.03W.

Table 1: Physical properties

	air	R134a	R123	HFE 7100
Molecular weight, g	29	102	153	250
Boiling point, °C	/	-26	28	61
Saturation pressure at 90°C, bar	/	31.96	6.34	2.33
Standard dielectric strength, kV/mm	2.56	~5	~5	~5
Sonic speed at the nozzle throat, m/s	~310	~137	~136	~110

3.2 Effect of nozzle size

Integrating the EGD electrodes into the nozzle has caused a large external size of the nozzle. It was a worry that the large size would reduce the suction ability of the ejector. A test was therefore carried out to compare the suction pressures of a normal brass nozzle and a bulky nylon nozzle. The results are shown in Figure 7. It can be seen that the difference in the suction pressure is very small. So the change in the nozzle outside size would have little effect on the performance of an ejector.

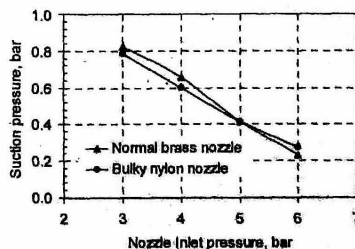


Figure 7: Suction pressure against nozzle inlet Pressure (air and 1bar back pressure)

3.3 Ejector performance

The performance of an ejector may be denoted by the entrainment ratio—the ratio of the suction flow rate to the nozzle flow rate. The liquid flow rates were measured using two flow meters at the condenser

outlet and the evaporator inlet. The condensation temperature was maintained at 30°C, and the evaporation temperature controlled at 5°C. R123, a medium pressure refrigerant, was used in the system. Figure 8 shows the change of the entrainment ratio with the boiler pressure. The entrainment ratio is at the peak when the boiler pressure is around 8bar. If the boiler pressure is higher, the nozzle flow rate will be larger and this would occupy more flow area in the diffuser; so the suction flow rate would be reduced. If the boiler pressure is smaller, the nozzle flow rate will be smaller, and so the nozzle flow has less momentum to entrain the suction flow, resulting in a smaller entrainment ratio. Figure 9 gives the results for HFE7100. The entrainment ratio is smaller than R123. The reason is that HFE7100 is a low pressure refrigerant and requires a larger diffuser diameter. As HFE7100 was tested on the ejector designed for R123, the entrainment ratio was smaller.

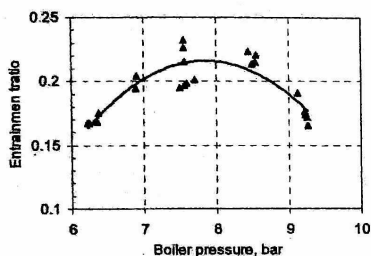


Figure 8: Entrainment ratio for R123
($T_c=30^\circ\text{C}$, $T_e=5^\circ\text{C}$)

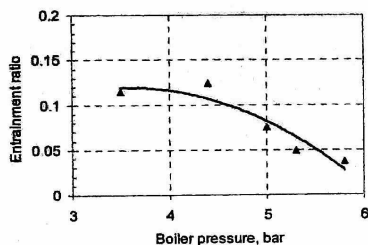


Figure 9: Entrainment ratio for HFE7100
($T_c=30^\circ\text{C}$, $T_e=5^\circ\text{C}$)

4. CONCLUSIONS

Incorporation of an electrogasdynamic (EGD) power generator with an ejector has been presented, designed and constructed. This combination has provided a novel means of combined heating, cooling and power generation systems. The EGD ejector has been tested for EGD conversion using air, R134a, R123 and HFE7100 as the working fluid. The EGD output power was about 0.1W for air and about 0.03W for other three. This power would be only useful in a high voltage application. The EGD ejector has a larger nozzle external size due to embedding the EGD electrodes, however, it has been found that the change in the nozzle external size had little effect on the performance of ejector. The EGD ejector has been also tested for cooling performance. On the experimental conditions, the maximum entrainment ratio was 0.22 for R123 and 0.12 for HFE7100.

ACKNOWLEDGEMENTS

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