Investigation of the performance of heat pipes used as capillary pumps

Zisis G. Diamantis, Dionysios I. Photeinos and Demos T. Tsahalis
Laboratory of Fluid Mechanics and Energy (LFME), University of Patras, Patras, Greece

Abstract This paper describes the investigation being performed by the Laboratory of Fluid Mechanics and Energy (LFME) in order to test the performance of heat pipes as capillary pumps. This investigation is part of the EU funded research project TRI-GEN EGD that aims in the development of a novel Tri-generation Electrogasdynamic converter system. The capillary pump will be used to pump the working fluid of the system using external waste heat. Furthermore, since the capillary pump has no moving parts it will provide the system with greater reliability. To this end, a Capillary Pumped Loop (CPL) experimental setup was designed and constructed by LFME. A CPL is a closed loop system that pumps liquid by passive means, based on the operating principles of heat pipes. Specifically capillary forces are generated on a porous structure that exists in the evaporation section and is responsible for pushing the working fluid from a high temperature source to a low temperature sink. In this paper the experimental setup constructed as well as the experimental procedure followed are described and preliminary results are presented.

Keywords capillary pumps; CPL; electrogasdynamic converter system

1. Introduction

The work described in this paper is being carried out as part of the EU funded research project, TRI-GEN EGD, which aims at the development of a novel Tri-generation Electrogasdynamic converter (TGEGC) system. The TGEGC system could be used to provide electricity, cooling and heating for buildings and industrial applications. It is based on the integration of an ejector refrigeration cycle with an electrogasdynamic (EGD) energy converter which is used to convert thermal energy into electrical power. The system could employ ‘ozone-friendly’ refrigerants such as water, methanol, ethanol, hydrocarbons or hydrofluoroethers (HFEs). In addition, the system has no moving parts and both ejector and EGD converter would be simple and reliable. The anticipated cost of production is low since inexpensive construction materials (e.g. copper or aluminum) could be used.

The capillary pump of the TGEGC system, investigated by the Laboratory of Fluid Mechanics and Energy (LFME) and presented in this paper, will be used to pump the working fluid of the system using external waste heat. The operation of the capillary pump is based on a Capillary Pumped Loop (CPL) system.

To this end, the present paper is structured as follows: initially a general description of the TGEGC system is given and a brief introduction to CPLs is made in order to familiarize the reader with the technology being used. Next, a detailed description of the experimental setup is given together with a description of the instruments that are used. The experimental procedure will then be described and finally some preliminary results will be presented.
2. General description of the TGEGC system and background theory on CPLs

2.1 General description of the TGEGC

As mentioned, the TGEGC (fig. 1a) system could be used to provide electricity, cooling and heating for buildings and industrial applications. The proposed system consists of an EGD ejector unit (single nozzle or multi nozzle) a capillary pump generator (which is considered as the vapour generator using an external heat source, such as waste heat for example), a condenser and an evaporator. The proposed system has no moving parts thus making it more robust and at the same time minimising the creation of noise and vibration.

The EGD converter part for creating electricity (fig 1b) consists of a corona electrode, a Venturi nozzle combined with an attractor electrode, and a condenser integrated with a collector electrode and works in the following way: initially the working fluid is vaporised in the generator and the vapour flows to the Venturi nozzle, expanding and partially condensing. As the under-saturated vapour passes through the space between the corona and the attractor electrodes at high a speed, the created liquid droplets are charged due to the high electrostatic field and form a charged aerosol. As this high speed charged aerosol flows through the electrical field existing between the two electrodes, the kinetic energy is converted to electrical power. After discharge, the neutral aerosol condenses by cooling and the liquid working fluid is in turn pumped back to the vapour generator.

In order for the system to incorporate cooling in addition to electricity production, the EGD converter part also contains an injection nozzle, a mixing section and

![Figure 1a. Schematic diagram of the TGEGC system, indicating the most important points.](https://academic.oup.com/ijlct/article-abstract/1/1/35/707966 by guest on 11 March 2019)
a diffuser. After passing through the nozzle, the high pressure vapour expands to a high velocity and low pressure stream which combines with low-pressure vapours from the evaporator causing a cooling effect. Both streams mix and diffuse to a higher pressure and condense in the condenser, which is placed right after the diffuser.

From the above described procedure it can be clearly seen that the system can be used to produce electricity and provide heating and cooling simultaneously.

Furthermore, as indicated above, there are no moving parts in the described system. Thus, with the introduction of a capillary circulation pump, the system would be completely passive. Such a pump would also reduce the number of components for the whole system because at the same the working fluid would be pumped and vaporised, thus there would be no need for an additional generator in the system. Up to now such pumps have only been used in the context of Capillary Pumped Loops (CPLs) and Loop Heat Pipes (LHPs) in which cases the operation is specifically oriented to transferring heat using a working fluid while in the present case the operation is specifically oriented towards pumping of the working fluid.

### 2.2 General theory on CPLs

A CPL is a closed loop system which uses passive means to pump its working fluid [1–10]. Its operating principle is based on the existence of capillary forces within a porous or wick structure in the evaporation section. These capillary forces are responsible for pushing the working fluid from a higher temperature area of the loop to a lower temperature area. The main difference from the heat pipes is that a wick/porous structure is needed only in the evaporator section of the CPL. CPLs are considered as reliable thermal management devices and are widely used for cooling electronic components. Furthermore, because of their passive nature, CPLs are especially used in space applications.
In figure 2, the basic components of a typical CPL are shown. These components are:

- An evaporator zone,
- A vapour transport line,
- A condenser zone,
- A liquid return line,
- A reservoir

Heat is provided through the evaporator which in turn vaporises the working fluid, while the condenser removes heat and condenses the fluid. The vapour transport line and the liquid return line transfer vapour and liquid, respectively, between the evaporator zone and the condenser zone. The reservoir, also known as the compensation tank, is used for controlling the operating temperature and also as for liquid inventory management.

The operating principle of a CPL is the following: Assuming that the loop is completely filled only with the working fluid in its liquid state, the evaporator is heated. As mentioned, the evaporator contains a porous or wick structure, which at this point has been completely filled with the working fluid. Thus when heat is initially applied, the liquid in the wick structure starts to evaporate and the capillary forces at the vapour/liquid interface start to develop. The vapours of the working fluid are then transferred through the vapour transport line to the condenser section where it is cooled and condensed. At the end of the condenser section, the liquid is subcooled to ensure that it will not vaporise before completing the cycle and reaching the evaporator section. Finally, through the liquid return line, the working fluid is returned to the evaporator and the cycle is repeated.

![Diagram](https://example.com/diagram.png)

Figure 2. Basic components of a CPL.
3. Experimental setup and procedures

3.1 Experimental setup
The experimental setup has evolved continuously during the investigation process. Initially, tests were conducted on a 70 cm long sintered material filled pipe and the liquid/vapour sections were approximately 7 m long, fig. 3. However, after some experience had been gained in starting up the system, it was decided to try a smaller/shorter configuration. This led to a reduction of the experimental setup to about one-third its initial size, i.e., liquid/vapour sections about 2.5 m long, fig. 4. Furthermore, in order to increase the flowrate, multiple, parallel evaporator configurations were tried in addition to the single sintered material filled pipe. Specifically, two 15 cm-long evaporator configurations, consisting of 3 and 7 sintered material filled pipes, respectively, bundled together were built. Currently tests are being performed on the 3-sintered filled pipe configuration, fig. 6.

The diagram of the experimental setup designed and developed by LFME is given in fig. 7. The description of its main components follows the numbering shown in figure 7:

#1. 10 liter compensation tank that contains a 1500 Watt heating resistor which is connected to an analogue thermostat for controlling the temperature of the water. The compensation tank is also equipped with a 0.5 m long high pressure, heat resistant glass tube in order to monitor the level of water in the tank (fig. 8).

#2, 10, 11 and 12. Ball valves for managing the filling up, start up and operation of the system.

#3. Filter for removing impurities from the working fluid.

Figure 3. Initial configuration of the experimental setup with the 70 cm sintered material filled pipe.
#4. Kobold KDF-1125-NV flowmeter (fig. 9) that has a measuring range of 1.2 lt/h to 12 lt/h, with maximum operating temperature of 80 °C and maximum operating pressure of 10 bar. The flowmeter works on the following known principle of rotameter flowmeters: a float (stainless steel ball) is placed inside a cone-shaped measuring glass. The float is raised due to drag forces to a certain level in proportion to the flow velocity of the medium.

#5 and 9. Kobold MAN-SF26 pressure gauges (fig. 10), P1 and P2, respectively, each with a cooling element. The operating pressure range is from 0 to 7 bar and
Figure 6. 15 cm long sintered material filled pipe.

Figure 7. Diagram of the experimental setup indicating the position of major components.

Figure 8. The 10 liter compensation tank.
the operating temperature range is −20 to 85 °C. The cooling element was placed to protect the pressure gauge from a medium that would have a temperature higher than 85 °C. These pressure gauges are used to measure the pressure of the working fluid before and after the evaporator section (sintered material filled pipe).

#6, 8, 13 and 14. Kobold TSA1105 Pt100 thermocouples (fig. 11), T1, T2, T3 and T4, respectively, used to measure the temperature of the liquid/vapour at the corresponding points. The maximum operating pressure of the thermocouple is 16 bar and the temperature range it can measure is −60 to 180 °C.

#7. The sintered material filled pipes and the heating coil. The heating coil is placed snugly around the downstream, 1/3 of the pipe (fig. 11).
#15. 10 liter suction tank. The purpose of the suction tank is to assist in achieving a high start-up temperature for the whole system.

#16 and 17. Kobold TWA R6A 03012P thermocouples placed on the surface, on each side of the sintered material filled pipe, with measuring range of −50 to 260°C, to monitor the temperature at the corresponding points (fig. 11).

#18. Kobold TWA R6A 03012 placed on the surface of the pipe in order to monitor the temperature at the condenser section.

#19. DVP LA 12 vacuum pump (fig. 12) for generating the required vacuum in the system before its filling up with the working fluid.

The pipes loop is made of 1/2 inch stainless steel pipe which can withstand pressures up to 12 bar. All pipe connections are sealed with Loxeal 18–10 liquid which when solidified can withstand pressures up to 60 bar and temperatures from of −50 to 150 °C. The liquid is fully compatible with the working fluid being used, which is water.

Finally, all pressure and temperature sensors are connected to a PC-based data acquisition system for continuous monitoring on the PC monitor and simultaneous digitization and storing.

3.2 Experimental procedure
First the system is flushed with distilled water to remove any impurities.

Then, the compensation tank is filled with distilled water in order to avoid having blocking phenomena later on in the sintered powder material due the presence of various unwanted minerals and salts in the water and its temperature is brought to the desired level.

During the heating of the water in the compensation tank, the vacuum pump is turned on until the desired level of vacuum has been achieved in the pipe system and the vacuum tank.
Then, with appropriate sequencing of the opening/closing of the ball valves #2, 10, 11 and 12, the pipe system and the sintered material filled pipes are filled with heated water from the compensation tank. In this operation, the purpose of the suction tank is to assist in filling up the system with high temperature water, needed for the start up.

Once the system is filled with high temperature water, the heating coil on the sintered powder material filled pipe is turned on. The temperature on the surface of the evaporator at its entrance and exit is monitored with the thermocouples #16 and 17, respectively. The pressure and the temperature of the water at the entrance to the evaporator and of the vapour at its exit are monitored with the pressure gauge and thermocouple #5&6 and #9&8, respectively. The temperature at the entrance, center and exit of the condenser is monitored with the thermocouples #13, 18 and 14, respectively.

Finally, the initiation of the flow and its subsequent development is monitored from the flowmeter #4 and by observing the behaviour of the level of the water in the glass tube of the compensation tank #1.

4. Preliminary results

The initiation of capillary flow in the evaporator was always observed after the temperature sensor #8 exceeded 100 °C, indicating the creation of vapour, as expected. However, the initiation of detectable flow in the pipe loop system was delayed a few minutes until the appropriate pressure had built up. It was manifested initially by oscillations of the water in the glass tube of the compensation tank which at times were rather strong reaching 5 cm peak to peak. Later on the ball in the flowmeter started rising and falling periodically, indicating flow, but with frequency less than that of the oscillations of the water in the glass tube (fig. 13). After isolating the compensation tank from the pipe loop, the oscillations of the ball in the flowmeter...
became stronger and more regular, indicating peak flow velocities between 1.2 to 2 l/hr.

When the configuration with the bundle of the 7 pipes filled with sintered material was tried, the flow even though it achieved larger peak velocities it was more unsteady than the case with the one pipe. Presently the bundle with the 3 pipes is being investigated.

The experience acquired up to now in operating the system is utilized to further improve the operating procedures, modify accordingly the whole system to achieve a fully flexible test bed and to design and test novel configurations of evaporators using simple elements of sintered material filled pipes in order to achieve higher flowrates with increased differential pressure capabilities.

Finally, it is envisaged to test working fluids other than water such as HFE7100, R134a and R142b.

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6. References