Optimization and testing of a first generation cavitation heat pump

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Introduction

Major objective of this project is to enhance the educational experiences of engineering students while working on a team project resembling a realistic work environment similar to that of and industrial setting. During 2012 summer vacation, 23 undergraduate students from three different universities (one private university, one city university and one state university) conducted 2012 summer undergraduate research activity. Theme of the 2012 summer undergraduate research activity was renewable energy systems. The summer undergraduate research activity was verbally advertized only throughout three mechanical engineering undergraduate classes of 2012 spring semester. However, 23 Undergraduates were applied to it even though the activity was unpaid, which proved show how attractive the topic, renewable energy systems, is nowadays. 23 students were grouped of 4 and chose their topics to work with. One of the topics was cavitation pump.

In this paper, four experimental setups are demonstrated to show how students clarify problems and find solution. The outcome of such learning experiences from this effort will be the design, implementation, theoretical analysis, model development and experimental application in the near future of an interdisciplinary project oriented course for engineering students. This course will involve concepts from fluid mechanics, heat transfer, electronics, finite element analysis, instrumentation, and data acquisition/analysis.

With growing environmental concern and the cost of energy rising, many cost effective and energy efficient technologies are developed. Such an example is heating water using conventional gas/electric water heaters or renewable energy such as solar power or geothermal power. Currently, most widely used method to heat water is by burning fossil fuels. This is often a large factor in determining the pollution caused by heating water for commercial or residential use. Despite the availability of renewable energy resources, the innovations that rely upon these alternative sources are not viable due to their uncontrollable nature and economic factors. In this paper, the cavitation heat pump serves as a promising beacon to engineers as it may be the answer as to how to heat water for commercial and residential purposes efficiently is introduced.

This cavitation pump directly converts electrical energy into thermal energy through cavitation induced by the rotation of the working fluid. The cavitation heat pump decreases the pressure of the working fluid, in this case water, to a point below its saturation pressure, which consequently induces cavitation. Energy is released in the form of heat when the bubbles collapse, causes the water temperature to rise.

Over the course of the project, thirty gallons of water was heated from 30°C to 70°C. The temperature, time, and the amperage were recorded at 5°C intervals and were analyzed to determine correlations between the measured parameters after each trial. The cost of heating using a cavitation heat pump was compared to that of conventional heating methods such as natural gas and electricity. The heating system, comprised of cavitation heat pump, the water tank, motor, pump, and piping, was altered after a few trials were conducted with a given setup to determine the optimal design and minimize the cost of heating.

In addition to the immense potential of the cavitation heater to serve as a means of heating water, cavitation heating effectively heats water uniformly without a temperature gradient between regions. Furthermore, the lack of a heat transfer surface prevents scale build up and ensures the heating of clean water.

Cavitation Heat Pump System Initial Setup

The cavitation heat pump system (see Figure 1) initially consists of an electrical motor, cavitation heat pump, water tank, piping, gauges, and all necessary peripherals. The electrical motor is interfaced with the cavitation heat pump using a rubber belt, which converts electrical energy into thermal energy through cavitation induced by the rotation of the working fluid. The cavitation heat pump decreases the pressure of water to a point below its saturation pressure, which consequently induces cavitation. Energy is released in the form of heat when the bubbles collapse, causes the water temperature to rise.

(a) (b)

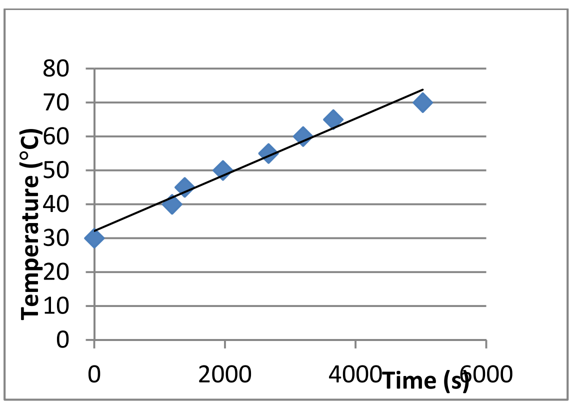
Figure 1: Cavitation heat pump setup; (a) electrical motor and cavitation heat pump, and (b) un-insulated water tank and gauges

This experiment demonstrates that thirty gallons of water is heated from 30°C to 70°C using the cavitation heat pump system. As water was heated, time and the amperage were recorded at every 5°C intervals. The measured parameters (See Table 1) were analyzed to determine correlations (See Figure 2) and cost of water heating (See Table 2). It ultimately culminated to cost of $0.92 and took one hour, twenty three minutes and twenty four seconds to heat thirty gallons of water from 30°C to 70°C. The cost of water heating using a cavitation heat pump will be compared to that of conventional heating methods such as natural gas and electricity later.

Table 1: Measured parameters (time, Amperage, and power) at every 5**°C** water temperature increase

Temperature Readings (°C)	Time Elapsed (s)	Cumulative Time (s)	Amperage (A)	Power (W)
30	0	0	43	9331
40	1190	1190	41.5	9005.5
45	194	1384	42	9114
50	584	1968	41.5	9005.5
55	698	2666	41.4	8983.8
60	530	3196	40.7	8831.9
65	462	3658	40.3	8745.1
70	1370	5028	41	8897

The initial setup of the cavitation heat pump system, however, was very crude. The water tank was not insulated, which in turn lead to significant heat loss from the heated water through means of convection and conduction with the ambient air. The use of excessive, un-insulated piping led to further heat loss and heat dissipation. In addition, circulating flow from the tank outlet and the cavitation heat pump inlet is purely depends on gravitational force without using any circulation pump, which causes slower flow through the system and increase the cavitation pump work to heat the water to the target temperature of 70°C.



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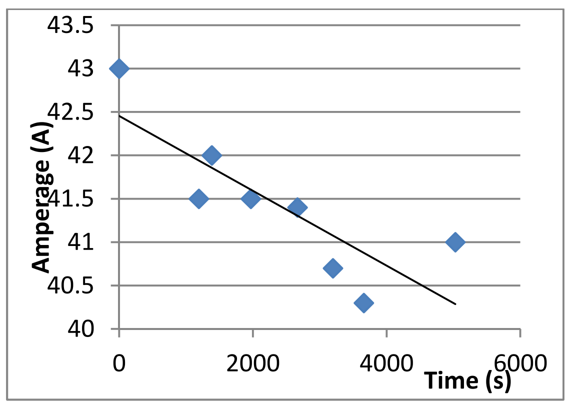

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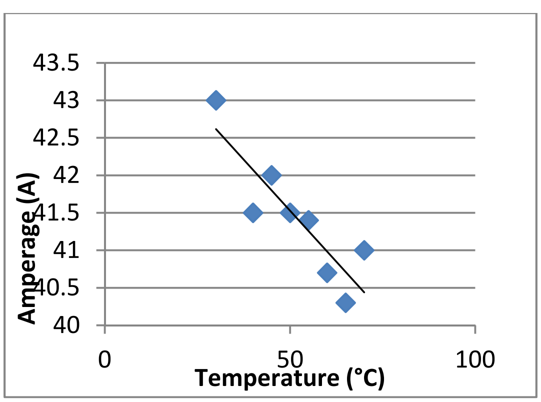

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Figure 2: (a) Temperature vs. time, (b) amperage vs. time and (c) amperage vs. temperature

Table 2: Water heating cost analysis

Average Power (kW)	8.989
Voltage (V)	217
Total Time (h)	1.39667
Price Rate of Electricity ($/kWh)	0.073089
Total Cost ($)	0.92

Cavitation Heat Pump System Second Setup

Cost of operation and heat loss were observed as relatively high using the cavitation heat pump system initial setup. Primary objective of this experiment is to minimize the time and cost required to heat the water through the forty degree temperature gradient. We hypothesized that this could be achieved by reducing the overall length of pipes and insulating the water tank and the pipe in order to reduce loss and heat dissipation. Another modification is that the outlet of the water tank was also moved to the lower most possible place of the water tank such that the coolest water at the bottom of the tank is able to enter into the heat pump. Among many modifications, use of a circulation pump to circulate the flow from the water tank to the heat pump increased the volumetric flow rate, which in turn increased turbulence and thus led to improve efficiency of heating cold water. Figure 3 shows modified cavitation heat pump system and Table 3 shows the measured data collected from the trial.

Figure 3: Cavitation heat pump setup to Increase efficiency and insulated tank

Table 3: Measured parameters (time, Amperage, and power) at every 5°C water temperature increase

Temperature Readings (°C)	Time Elapsed	Time Elapsed (s)	Cumulative Time (s)	Amperage (A)	Power (W)
30	0	0	0	70	15190
35	2:44:00	164	164	69.5	15081.5
40	4:49	125	289	68.8	14929.6
45	8:17	208	497	68.3	14821.1
50	10:46	149	646	67.6	14669.2
55	13:59	193	839	67.4	14625.8
60	15:17	78	917	67	14539
65	19:48	271	1188	66.4	14408.8
70	22:11	143	1331	65.8	14278.6

The modification of the cavitation heat pump system was proven to be more effective such that it only costs $0.40 to heat the water to the target temperature of 70°C, which is a 56.2% reduction compared to the initial system setup. In addition to the cost reduction of operation, it only took twenty two minutes and eleven seconds, which is a 73.5% reduction compared to the initial system setup. Furthermore, Figure 4 shows stronger linear correlation between time, temperature and the amperage. Hence, it is proven that the insulation on the pipes and the water tank enabled the system to better retain the heat.

However, it was observed that the heated water provided from the heat pump was contaminated. This was due to the broken mechanical seal composed of carbon that eroded into the heat pump and mixed into the water. The purpose of the mechanical seal was to prevent water leaks along the rotating shaft. Consequently, the system would have most likely performed better had it not leaked and thus lost thermal energy and mass from the working fluid.

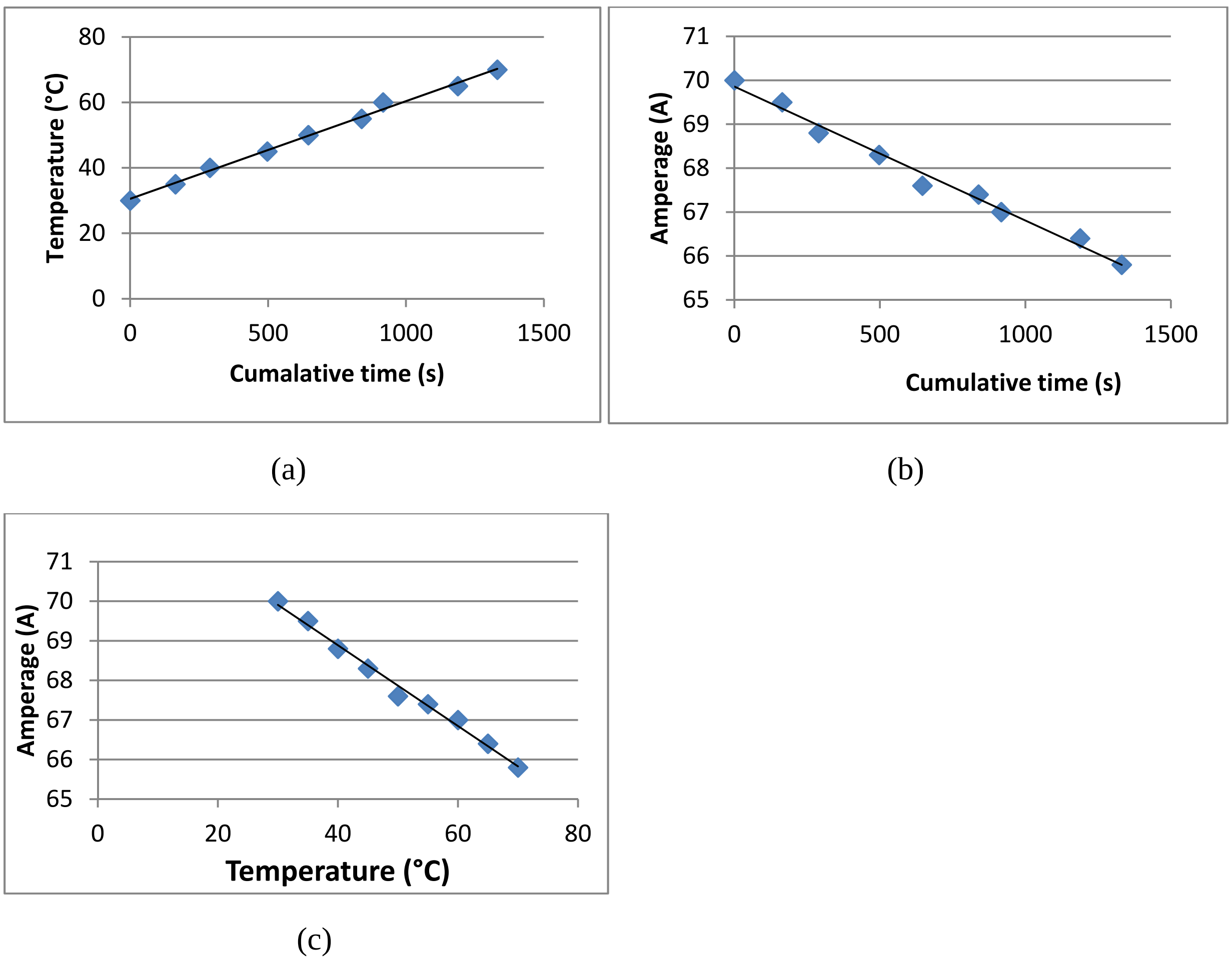


Figure 4: (a) Temperature vs. time, (b) amperage vs. time and (c) amperage vs. temperature

Table 4: Water heating cost analysis

Average Power (kW)	14.727
Voltage (V)	217
Total Time (h)	0.37
Price Rate of Electricity ($/kWh)	0.073089
Total Cost ($)	0.40

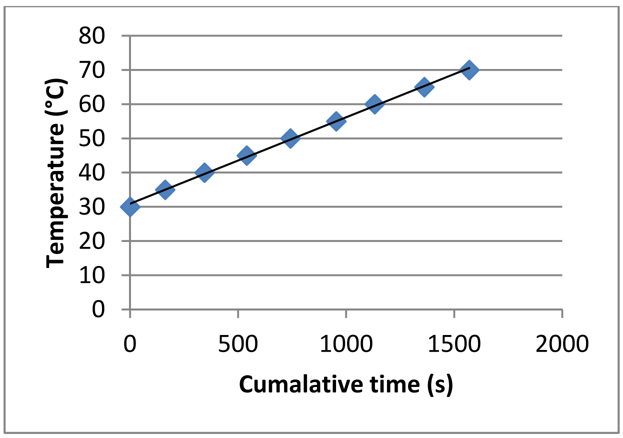
Cavitation Heat Pump System Third Setup

In the third experiment, the discharge pipes from the cavitation heat pump were switched from a flexible rubber pipe to a solid metal pipe. The pipes were left un-insulated to determine how much heat the water would lose due to the pipe change. The discharge pipes also had the ability to split the water into three paths (see Figure 5). Each path had a different pipe diameter so that the effect of a lower Reynolds Number on the rate of heat loss through the pipe could be determined. The mechanical seal that was discovered to be broken during the second trial was removed, which lead to a large amount of the working fluid to be lost during operation due to the fact that there was no seal for the water around the shaft. Because of the limited amount of piping that was at hand, the outlet pipe was forced to return to a higher exit point so the water that was being returned into the water tank experienced less mixing. Also starting this trial, the top of the water tank was covered off with a wooden sheet to minimize heat loss through the steam escaping from the top of the water tank. The water circulating pump provided the volumetric flow rate in addition to gravitational force. Figure 5 below shows the third setup of the cavitation heat pump system.

Figure 5: Cavitation heat pump setup to Increase efficiency, solid pipe connections and insulated tank

Table 5: Measured parameters (time, Amperage, and power) at every 5°C water temperature increase

Temperature Readings (°C)	Time Elapsed	Time Elapsed (s)	Cumulative Time (s)	Amperage (A)	Power (W)
30	0	0	0	68.7	14907.9
35	2:42:00	162	162	66.4	14408.8
40	5:44	182	344	62.1	13475.7
45	9:00	196	540	60.6	13150.2
50	12:22	202	742	58.9	12781.3
55	15:54	212	954	58.5	12694.5
60	18:52	178	1132	58	12586
65	22:42	230	1362	57.9	12564.3
70	26:10:00	208	1570	57.9	12564.3



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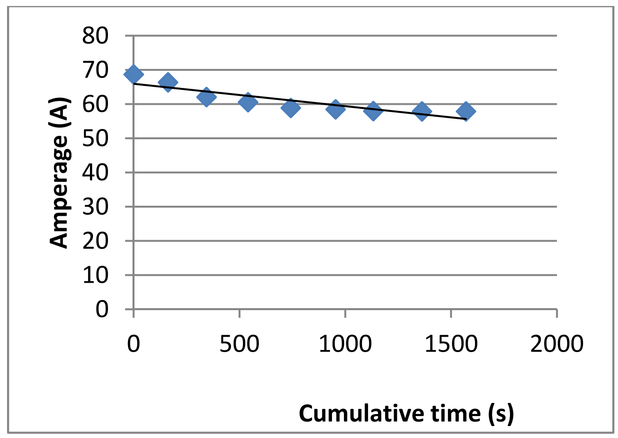

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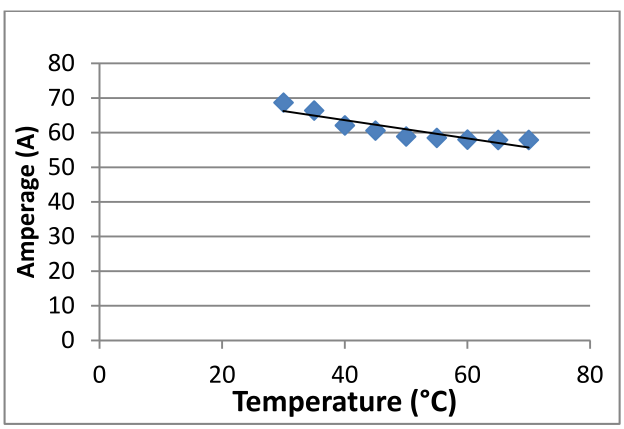

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Figure6: (a) Temperature vs. time, (b) amperage vs. time and (c) amperage vs. temperature

Table 6: Water heating cost analysis

Average Power (kW)	13.237
Voltage (V)	217
Total Time (h)	0.44
Price Rate of Electricity ($/kWh)	0.073089
Total Cost ($)	0.42

In this experimental setup, the cost of heating water using the cavitation heat pump system rather increased by 5% (from $0.40 to $0.42) compared to the second system setup. The time for the heat pump to finish heating up the water took twenty six minutes and ten seconds, an 18.11% increase compared to the second system setup. This efficiency reduction was expected as there was a water leak due to no mechanical seal on the shaft. Due to the unsteady state of the rate of mass lost through the leak, the correlation between the amperage and time were lower.

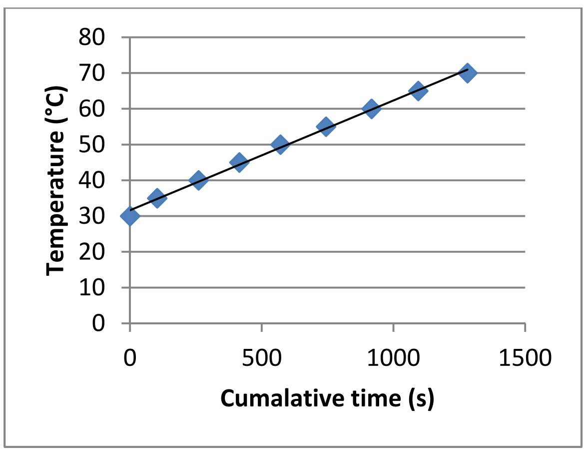
Cavitation Heat Pump System Fourth Setup

In the final experimental setup, following modification is applied to the cavitation heat pump system to increase overall efficiency. First, location of the water tank was elevated so that more gravitational force provided to help increasing the flow rate of the water into the heat pump. The rationale behind this was determined by Bernoulli's Principle, which states that higher the elevation of the working fluid, the more energy it contains. This extra energy means a higher velocity due to gravity. The water circulating pump that originally placed on the input pipe line was relocated to the discharge pipe line so that it would assist the water back up to the pump due to its higher elevation. The mechanical seal was not still provided since it was broken for this setup and thus due to the unsteady rate of mass lost from the working fluid, inconsistencies in the readings were expected. The discharge pipes from the heat pump were insulated during this setup to reduce heat loss along the metal discharge pipes.

Figure 7: Cavitation heat pump setup to Increase efficiency, elevated water tank and insulated discharge pipes

Table 7: Measured parameters (time, Amperage, and power) at every 5°C water temperature increase

Temperature Readings (°C)	**Time Elapsed (s)**	**Cumulative Time (s)**	**Amperage (A)**	**Power (W)**
30	0	0	70.3	15255.1
35	103	103	69.4	15059.8
40	157	260	69.3	15038.1
45	155	415	69.2	15016.4
50	156	571	68.8	14929.6
55	173	744	68.3	14821.1
60	173	917	67.4	14625.8
65	177	1094	67.2	14582.4
70	187	1281	65	14105



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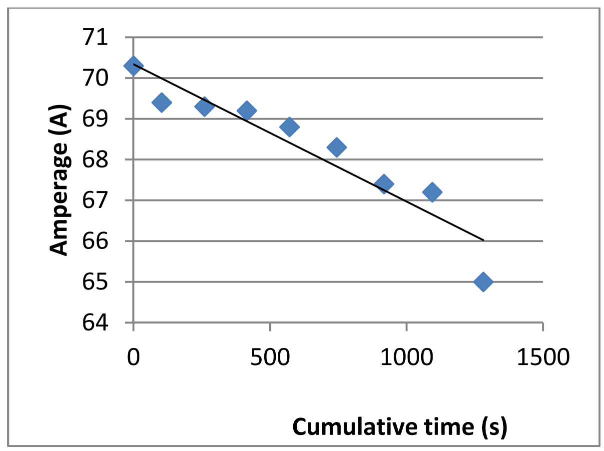

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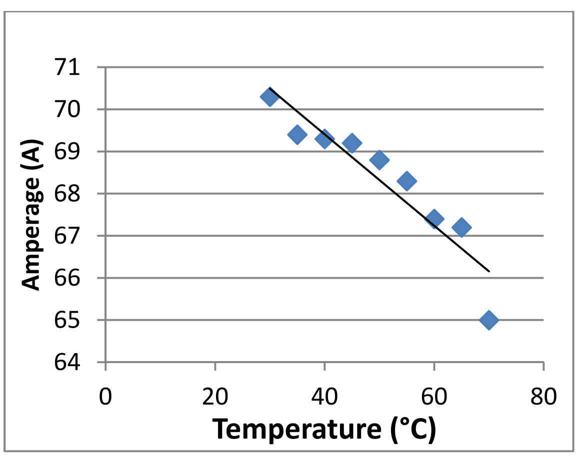

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Figure8: (a) Temperature vs. time, (b) amperage vs. time and (c) amperage vs. temperature

Table 8: Water heating cost analysis

Average Power (kW)	14.826
Voltage (V)	217
Total Time (h)	0.36
Price Rate of Electricity ($/kWh)	0.07309
Total Cost ($)	0.39

The modification of the cavitation heat pump system during fourth experiment was proven to be more effective such that it only costs $0.39 to heat the water to the target temperature of 70°C, which is a 7.14% reduction compared to the second system setup. In addition to the cost reduction of operation, the total time took for the heat pump to heat up the water was twenty one minutes and twenty one seconds, which was a 18.41% % reduction compared to the second system setup. As expected, due to the unsteady amount of mass lost due to the leak, the correlation between the parameters were weak and did not fit into the linear model that was being observed in the second trial.

Conclusion

In this paper, cavitation heat pump system is developed to heat water. The four experimental setups and modifications were presented to illustrate the efficiency enhancement potential of the cavitation heat pump system. Throughout the four experimental setups and modifications, the total costs of heating the water by using the cavitation heat pump came out to $0.92, $0.40, $0.42, $0.39, which is quite closed to current energy cost.

These four experimental setups/modifications also illustrate how to enhance the educational experiences of engineering students using mechanical engineering concepts from fluid mechanics, heat transfer, electronics, finite element analysis, instrumentation, and data acquisition/analysis. The outcome of such learning experiences from this effort can be expanded to the design, implementation, theoretical analysis, model development and experimental application in the near future of an interdisciplinary project oriented course for engineering students.

After the summer research activity, two groups of students still continue to conduct research. One of the groups is trying to patent their research result. . Another group is currently competes University Innovation competition using the 2012 summer research activity result and won the first round and currently at the semi-final. In addition, new course (renewable energy system) is able to be offered to undergraduate students in spring 2013 semester by integrating all of the summer research effort.