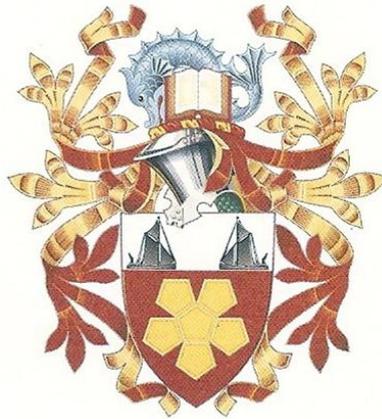


COMPARISON OF THE HEAT TRANSFER THROUGH HYDROMX WITH THAT OF WATER

WITNESS REPORT ON EXPERIMENTAL TESTS



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Summary

Space heating and hot Water usage account for over 50 % of the energy demand in buildings. The energy used to provide the required heat is dependent on many factors including the efficiency of the heating system, efficiency of the heat exchangers and the thermodynamic and hydrodynamic characteristics of the heat transfer fluid. The availability and low cost have kept Water as the number one heat transfer fluid in commercial and domestic traditional heating systems, while the potential for long term energy savings by using alternative fluids with better heat transfer characteristics has taken a back seat.

This report presents an independent account of an experimental investigation performed in the presence of the authors to compare the heat transfer performance of a 50 % Hydromx/Water mixture with that of 100 % Water.

The report begins with an overview of the experimental setup and procedure used, followed by analysis and assessment of the results obtained.

A simple two column heat transfer test apparatus, designed, assembled and instrumented by KODEM Ltd in Turkey was used to carry out the comparison. The full test facility including the monitoring system was inspected and checked by the authors of this report before witnessing the test.

Data collected during the experimental investigations were made available to the author for further analysis and to develop this witness report.

Both witnessed visual and analysed results showed that the sensible response of the Hydromx mixture to the presence or removal of heat was quicker than the response of the 100 % Water and at the end of the heating cycle the total heat energy transferred by the Hydromx was approximately 37 % higher than that for the 100 % Water for this particular test.

1. Introduction

In the UK about half of all CO₂ emissions produced is due to energy usage in buildings, with both space and domestic-Water heating accounting for over 50 % of the energy demand of buildings. Efficient heating systems are important in saving energy and CO₂ emissions with the efficiency of the heat generators, heat exchange components and the hydrodynamic and thermodynamic characteristics of the energy carrier fluid (heat transfer fluid) all contribute to making an efficient heat system.

Heat-transfer fluids carry heat from the heat generator to either the storage tank or to the heat exchangers or radiators. When selecting a heat-transfer fluid, engineers have to weigh a number of factors and criteria including, economic, environmental and safety factors as well as the thermodynamic and hydrodynamic criteria of the fluid. The main thermodynamic and hydrodynamic criteria are the coefficient of expansion, viscosity, thermal capacity, freezing and boiling and flash points and these properties directly affect the safety, movement and the heat transfer effectiveness of the fluid. Other properties that help determine the effectiveness of a fluid in a heating system are its corrosiveness and stability.

Water is still one of the most commonly used heat transfer fluids in wet heating systems with advantages such as availability, low cost, non-toxicity, low viscosity and high specific heat. However, Water suffers from two serious drawbacks. It has a relatively low boiling point, high freezing point and can cause corrosion if the pH (acidity/alkalinity level) is not maintained close to neutral (pH 7). Also Water with a high mineral content (i.e. "hard" Water) can cause mineral deposits to form within the system. Foaming and nucleate evaporation of Water in heating systems can cause aeration in radiators and thus reducing the rate of heat transfer and their effectiveness. Therefore, there is a need for a safe, economic and effective heat transfer fluid, which would also help save energy.

PBA Energy Solutions Ltd are distributing a new heat transfer fluid "Hydromx", which is being promoted as a replacement for Water in heating and cooling systems. It is claimed that Hydromx will enhance the heat transfer rate in wet heating systems and thus aid fuel economy. While there are case studies reporting that Hydromx delivers energy efficiency savings of up to 35% as claimed, there has been no independently witnessed assessment of

the fundamental heat transfer properties that underpin the claimed savings. The Department of Urban Engineering, London South Bank University consulted on the design and implementation of the test assembly and test plan to prior witnessing the tests and results.

2. Aim and Test Objectives

The main aim of the present report is to provide an independent witness account and expert opinion relating to an experimental investigation designed, set-up and performed at KODEM Ltd to compare the heat transfer of 50% Hydromx/Water mixture with that of 100 % Water.

Test Objectives:

- To compare the heat transfer through single phase 50 % Hydromx/Water Mixture with that for 100 % Water.
- To understand the heat transfer mechanism of Hydromx

3. Descriptions of the Test Apparatus

The test apparatus was designed and constructed with the aim to provide a simple test facility that could simultaneously compare the heat transfer through two different fluids when they are subjected to the same heat source and the same environmental conditions. The two fluids compared in this study are 50 % Hydromx/Water mixture and 100 % Water. It was important for the chambers used for both fluids to be constructed of the same material and to have the same volume, and same instrumentation. This was ensured by developing the device shown in Figure 1 and described below.

As can be seen from Figure 1, the test apparatus consists of four main sections duplicated for both fluids. Section 1 is the heat source (common for both columns), section 2 is the fluid test chambers, section 3 is the heat transfer element and section 4 is the heat sink

chambers. Both the test chambers and the heat sink chambers are constructed from double walled polycarbonate tubes, and are described in more detail below.

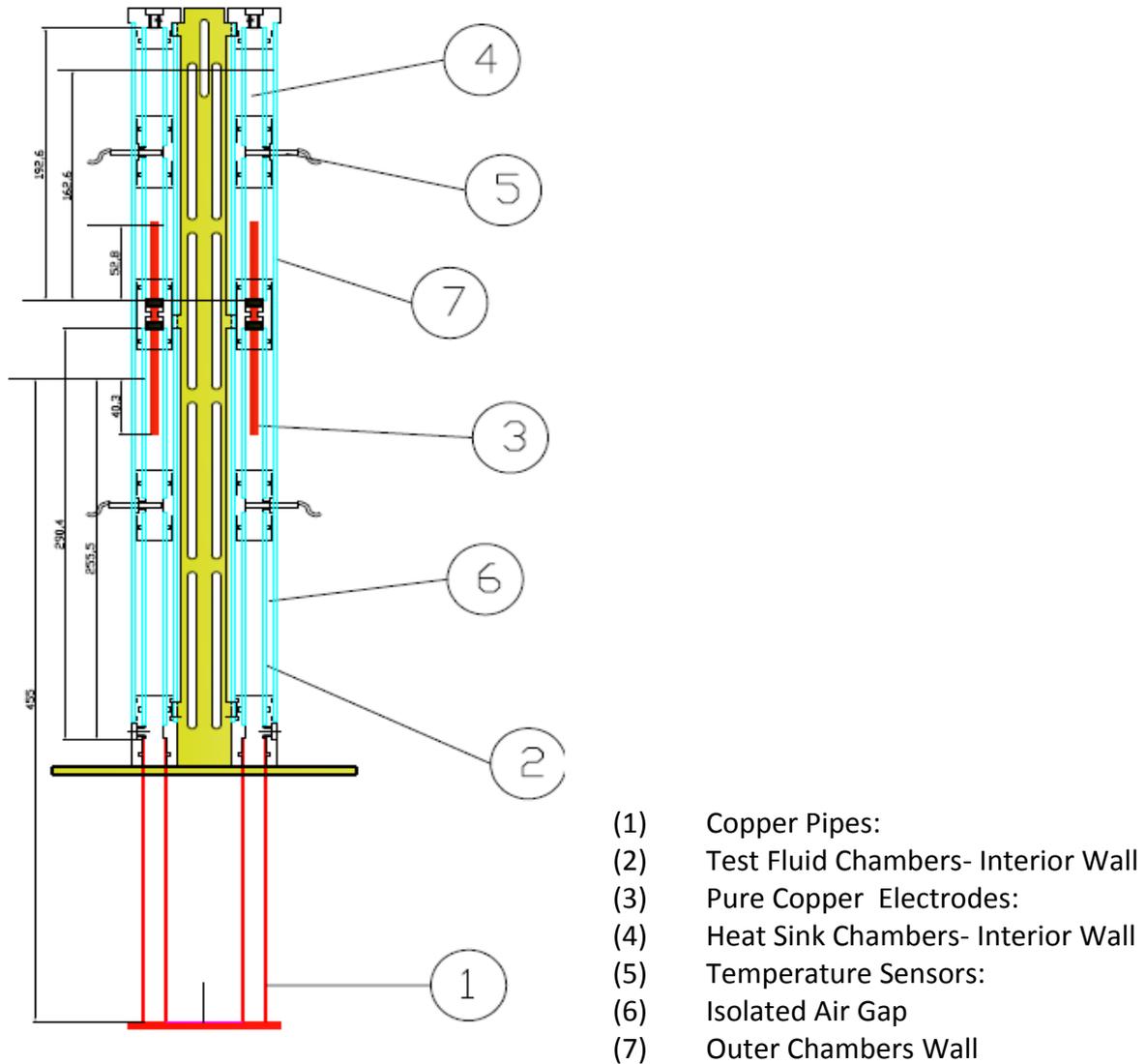


Figure 1: Schematic of the test apparatus

The heat source section is an electrically heated Water vessel which can be maintained at a constant temperature. When heated the vessel provide the source of heat simultaneously to both test-fluid chambers and at the same time.

The heat transfer fluid chambers are constructed from two twin-wall polycarbonate tubes (290.4 mm in length); each linked at the base to a 200 mm Length capped copper tube. The

Internal and external diameter of the polycarbonate sections were 11.65 and 30 mm respectively, with an air gap of 5 mm between the inner and outer walls. The internal and external wall thicknesses of the twin-wall polycarbonate tubes are 4.35 and 4 mm respectively.



Figure 2: The two column experimental apparatus.

Both base copper elements are the same diameter and the same thickness and were cut from the same tube length. Copper is a good conductor and hence the two base elements are used to conduct heat from the heat source vessel to the heat transfer fluids inside the test chambers. The internal and external diameters of the copper elements are 14 mm and 16 mm respectively. The internal volume of each chamber (polycarbonate tube plus copper element) equated to 56.8 ml.

The two polycarbonate sections with the capped Copper bases were held vertically side by side on a plastic frame using cable ties and used as the holding columns for the two fluid mixtures to be compared. Column 1 contained 56.8 ml of 100 % Water and column 2 contained 56.8 ml of Hydromx mixture (50 % Hydromx/Water mixture).

4. Description of the Data Acquisitions System

The temperature monitoring was carried out using J-type thermocouples, located at three main positions for each column: at the heat source (the kettle Water temperature) which was a common heat source for both heat transfer fluids; at the heat transfer fluid chambers; and at the heat sink chambers. All thermocouples were connected to a data logging system (HiLOGGER Hioki 8422-50) which was set up to monitor and record the temperatures for the thermocouples in real time, at set intervals. See Table 1 for more details on the thermocouple locations and channels descriptions.

Table 1: Channel descriptions used in the data logging system for Hydromx and Water comparison tests

Channel 1	Ambient Temperature.
Channel 28	Heat Source Temperature, Water Inside the kettle.
Channel 29	Lower Temperature of 100 % Water
Channel 30	Upper Temperature of 100 % Water
Channel 31	Lower Temperature of Hydromx mixture
Channel 32	Upper Temperature of Hydromx mixture

Five additional K-type sensors were placed in the same vicinity as the J-Type thermocouples, and linked to a digital temperature display to provide instantaneous visual monitoring of: the temperatures of the fluids; the heat source; and the environment.

5. Test Procedure

The same amount of heat was applied simultaneously to both heat transfer fluids by immersing the base of the two columns into an electrically heated vessel with a thermal controller. The heat source was heated from ambient to approximately 96 ± 1 °C and kept at this temperature until steady state conditions were achieved for approximately 30 minutes. The heat source was then switched off and the system was allowed to cool down back to ambient. Temperature changes with respect to time in the tested fluids and heat sink chambers as well as the ambient and heat source temperatures were all monitored and recorded every second for the entire experiment. Care was taken to ensure that the copper base of both columns was immersed to the same height in the heat source vessel and that no other heat or light source was directed onto either of the columns.

6. Results and Discussion

In this chapter, the visual observation and experimental results are presented and discussed.

6.1 Visual Observations

Prior to the immersion of the two column apparatus in the heat source/reservoir, all of the thermocouples and probes in the same vicinity registered similar temperatures, and all of the temperatures were close to the ambient temperature.

Following immersion of the base of the two columns in the heat source/reservoir, it was noted that it took about 50 seconds for both base temperature recorders to register a rise in temperature, followed by some visible particle movement near the base of the Hydromx column. Two minutes after the initial immersion, clear convection currents were visible in the Hydromx column. However, this was not visible in the 100 % Water column. The convection current in the Hydromx became clearer (in the middle of the column) as time passed with almost half of the tube showing a rising current while the other half showed a falling current. The presence of a red dye may have been a factor in the clearer visibility of

the convection currents within the Hydromx mixture column, compared to that in the 100 % Water column.

6.2 Analysis of Results

Figure 3 presents the recorded temperatures with respect to time for the heat source, heat transfer fluids in both chambers and the heat sink chambers. By comparing the temperatures at the beginning of the experiments, it is clear that the temperatures recorded by all the thermocouples before immersion were very similar and that the variation in ambient temperature recorded was within the thermocouples' manufacturer quoted uncertainty values

Following immersion in the heat source, the Hydromx mixture responded to the applied heat after 50 seconds while the 100 % Water responded after approximately 90 seconds. This was in line with the visual observations reported via the digital displays.

For the upper temperature sensors, the first temperature reaction for the thermocouple located in the Hydromx heat sink occurred after 290 seconds while the Water heat sink temperature did not start rising until 350 seconds after the start of the experiment.

Although both fluids seemed to follow similar heating and cooling profiles, it is clear from the data trace that the temperature rise for the Hydromx mixture is much faster and higher in value than that for the 100 % Water fluid at any particular time after the initial temperature rise. If we consider the steady state regions (the red and blue circles in Figure 3, it is clear that the temperatures recorded in the Hydromx column are approximately 10 °C higher than the temperatures reached by the 100 % Water fluid under the same heating conditions and at the same time period. Similarly, the temperature of the Hydromx heat sink is approximately 5 °C higher than that of the Water only heat sink.

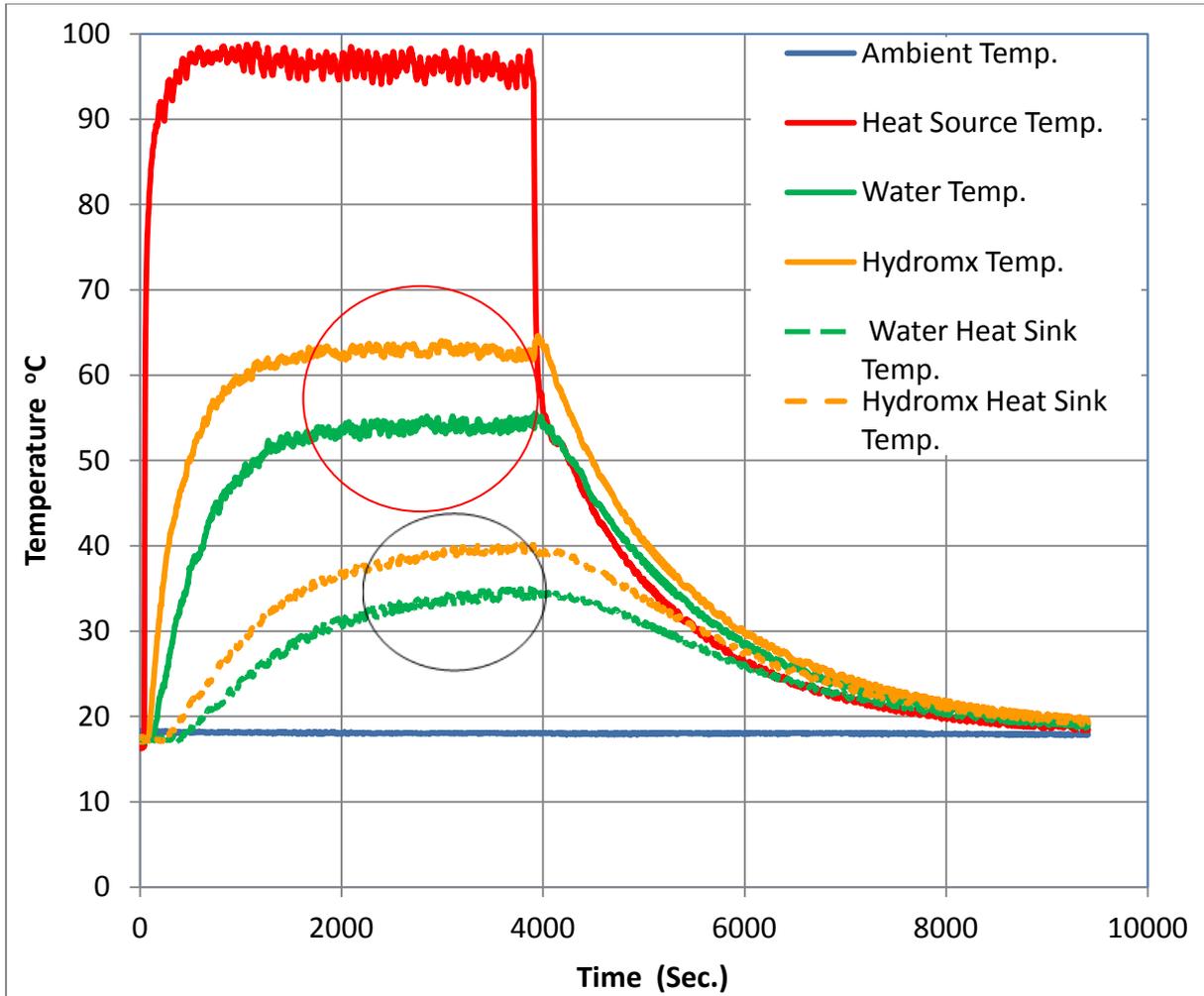


Figure 3: Comparison of the sensible temperature response of Hydromx mixture compared to 100 % Water.

Figure 4 presents the calculated cumulative heat energy gained by the heat sinks as a result of heat transfer through the fluids subjected to the test. The calculation of the energy gained by the heat sinks was based on the sensible heat gain equation ($Q = m C_p \Delta T$), where m is the mass of the Water in the heat sinks which is 16 grams for each heat sink, C_p is the specific heat capacity of Water taken to be 4.187 kJ/kg K (at 22 °C) and ΔT is the temperature rise of the heat sinks relative to the starting temperature. As can be seen from the Figure, the calculated total energy profiles for both heat sinks follow the same trend. However, for any period of time the calculated energy transferred to the Hydromx heat sink was calculated to be higher than that for the Water heat sink. This is a clear indication that more heat energy was transferred through the Hydromx column than through the Water column for the same time period.

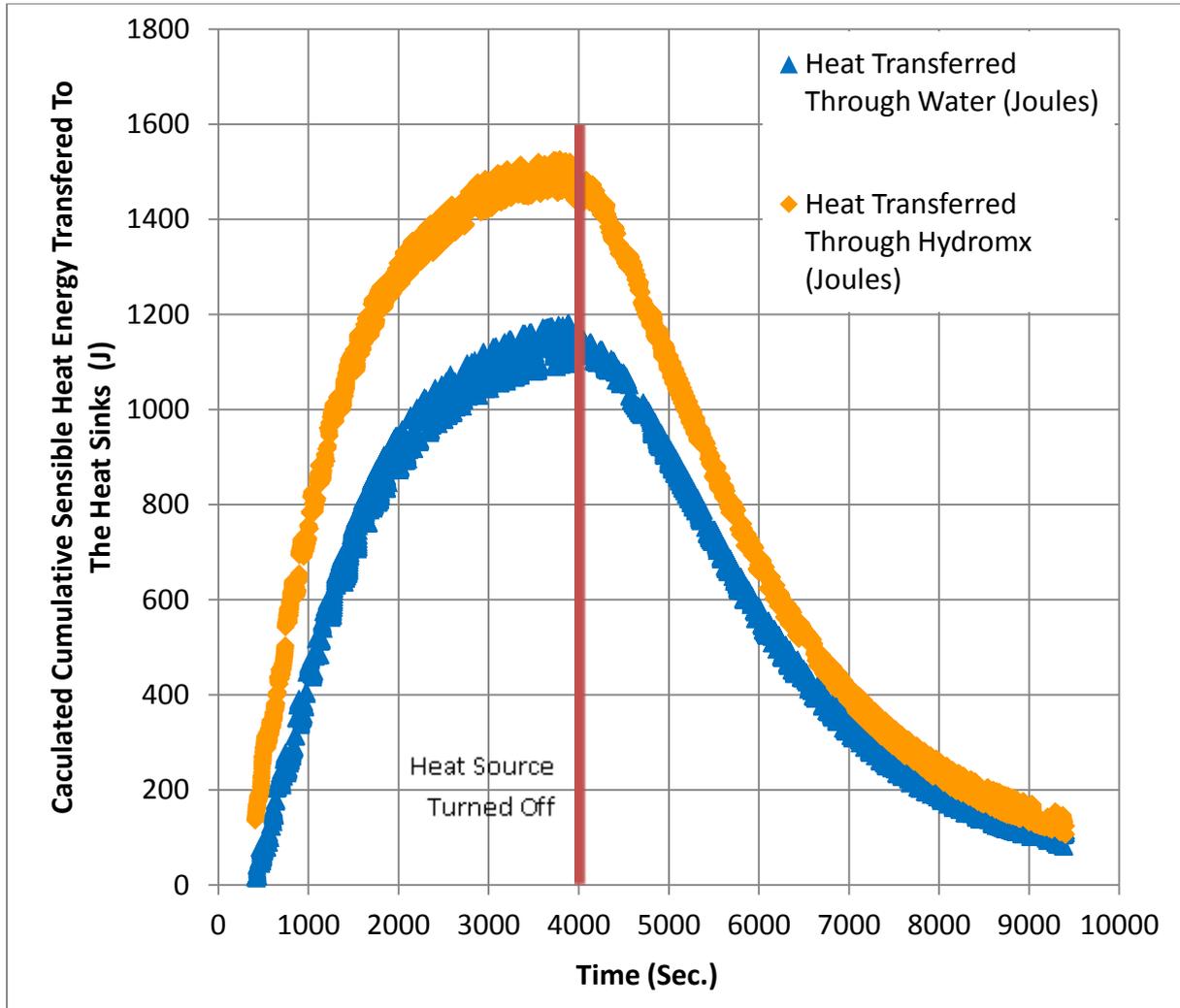


Figure 4: comparison of the cumulative heat energy gained by the heat sinks as a result of heat transfer through the tested fluids.

Figure 5 present the heat transfer rate to the heat sinks versus time. It is clear from the Figure that the calculated heat transfer rates start and finish at the same level (i.e. before heating and at the end of the cooling cycle). However, the heat transfer rate to the Hydromx heat sink is always superior to the heat transfer rate to the Water heat sink, especially in the region between 1000 and 2000 seconds, where the heat source temperature was at the maximum set-point (approximately 96 ± 1 °C).

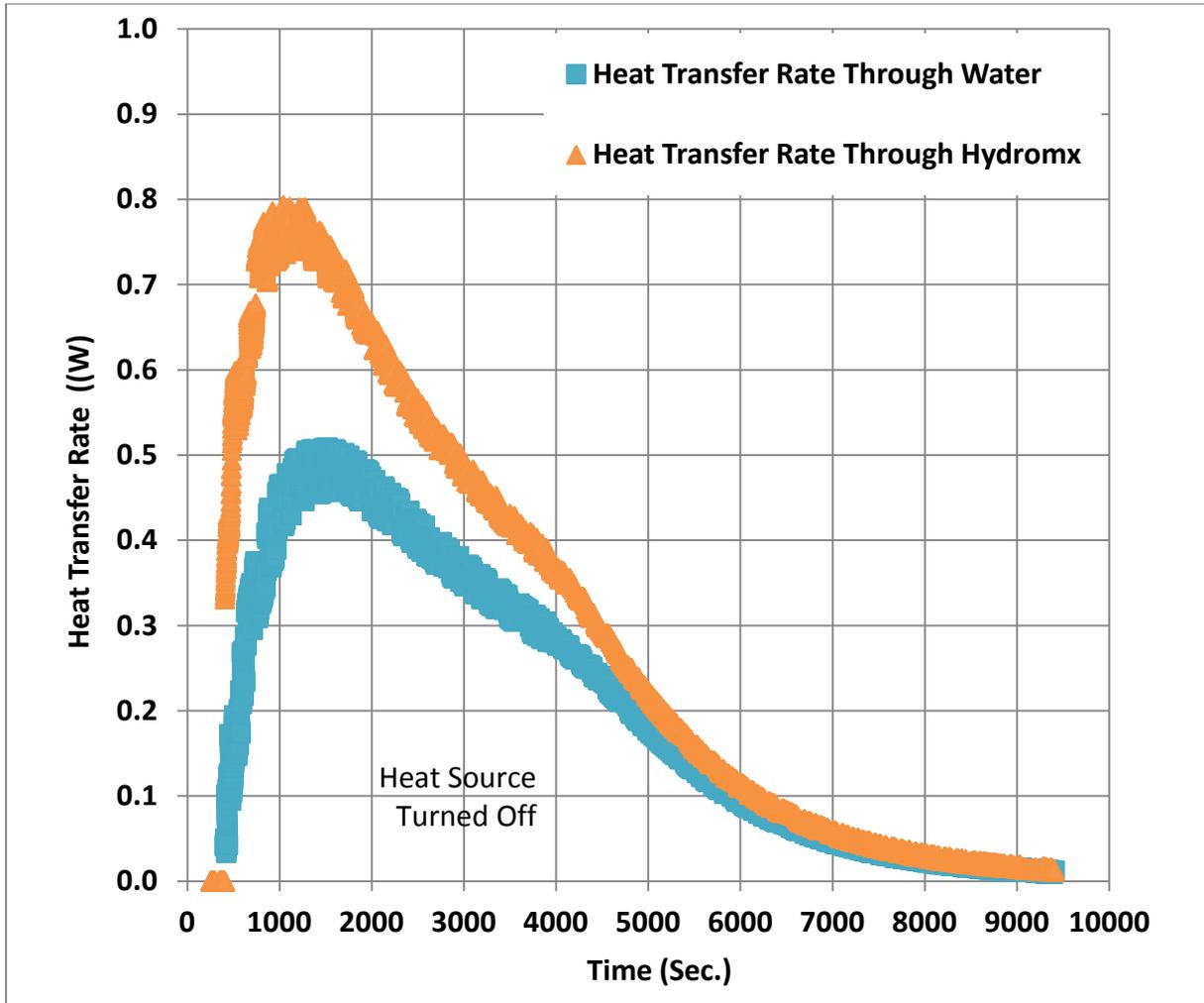


Figure 5: Variation of the heat transfer rate through the Hydromx mixture compared to 100 % Water with respect to time, based on the start temperature.

Figure 6 presents a comparison of the heat transfer rate with respect to the heat source temperature during the cooling period. The heat transfer rates were calculated using the cumulative heat energy transferred to/from the sinks and the time from the start of the experiment. It is clear from Figure 6 that the heat transfer rate for Hydromx is higher by approximately 37 % around the 96 °C heat source temperature region. As the heat source temperature decreases, and the temperature differentials decrease, the heat transfer rate for both fluids naturally converges.

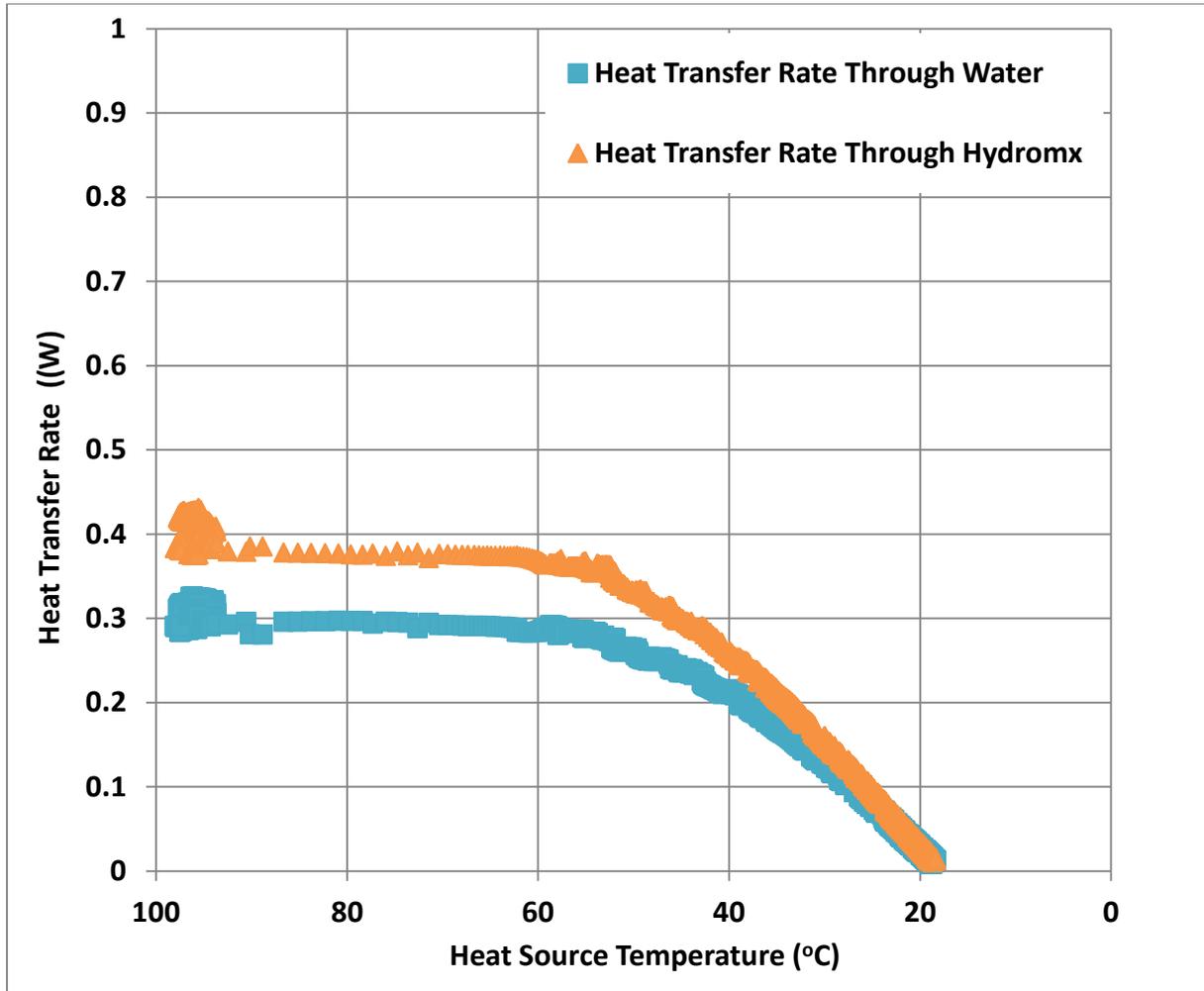


Figure 6: Variation of the cooling heat transfer rate through the Hydromx mixture compared to 100 % Water with respect to the heat source temperature.

7. Conclusions

Comparison between the heat transfer through 50 % Hydromx/Water fluid mixture with that through 100 % Water was carried at KODEM Ltd using a two column apparatus with the temperatures of the heat source, heat sinks, tested fluids and ambient all simultaneously monitored and recorded. Both the 50 % Hydromx/Water mixture and the 100 % Water were subjected to the same heat source by immersing the base of the two columns into an electrically heated vessel with a thermal controller. The heat source was heated from ambient to approximately 96 ± 1 °C and kept at this temperature until steady state conditions were achieved for approximately 30 minutes. The heat source was then switched off and the system was allowed to cool down back to ambient. The experiment was

witnessed by the author and the following conclusions drawn from the recorded data and visual observations:

- i) The temperature and time results revealed that the tested sample of Hydromx/Water mixture reacted (with an increase in temperature) to the applied heat approximately 40 seconds before the 100 % Water both under the same test conditions.
- ii) During the steady state period and with both fluids subjected to the same heat source, the temperature reached by Hydromx/Water mixture was approximately 10 °C higher than that of the 100 % Water.
- iii) The difference in total energy transferred to the heat sinks up to and including the steady state period (i.e. after 3870 second from the start of experiment) was calculated to be 37 % higher through the Hydromx column than that through the Water column.
- iv) The quicker response of the Hydromx/Water mixture gives it an advantageous position in terms of heat transfer when compared to Water alone in both heating and cooling application.

8. Recommendations

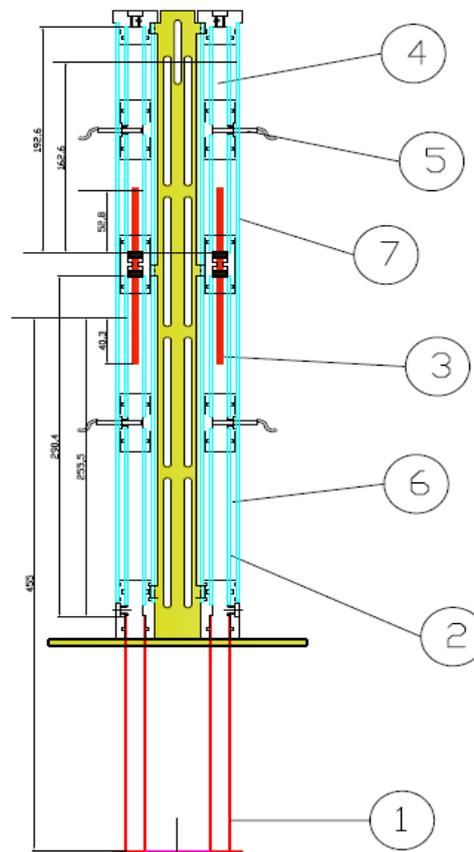
More tests are required to provide a full thermodynamic and hydrodynamic understanding of the Hydromx mixture including formal determination of the coefficient of expansion.

Further test are required to investigate Heat Transfer using a typical gas boiler so that results can be interpreted to real world installations. Ideally these tests would identify the optimum boiler (heat source) operating temperatures and suitability for applications with Heat Pumps (Air Source, Ground Source etc), and Solar Thermal systems.

Appendices

Appendix- A: Technical Specifications of Heat Transfer Demo Device, As supplied by KODEM Ltd:

The heat transfer demo device consisted of 5 thermocouples to measure the temperatures of the liquids separately, while Water was boiling in the kettle. There were two thermocouples located at the bottom of the tubes to measure the temperatures of the Hydromx mixture and Water respectively, and a third thermocouple is used to measure the temperature of the boiling Water in the kettle. Furthermore, the thermocouples at the top end of the tubes were used to measure the temperature of the Hydromx mixture and Water respectively at this location. The aim was to measure the temperatures of the liquids at the top end of the columns in order to compare the rates of heat transfer in the Hydromx mixture and Water alone.



1 Copper Pipes:

- i. External Diameter: 16 mm
- ii. Internal Diameter: 14 mm
- iii. Height: 200 mm
- iv. Weight: 80 g
- v. Internal Volume: 30.772 ml

2 Fluid Chambers Interior Wall Polycarbonate Lower Pipes:

- i. External Diameter: 16 mm
- ii. Internal Diameter : 11.65 mm
- iii. Total length of lower chamber: 290.4 mm
- iv. The liquid level to be measured : 255 mm

The liquid to be measured:

1- Lower copper pipe 200 mm -----	30.772 ml
2- Polycarbonate Pipe 255 mm-----	27.168 ml
TOTAL-----	57.94 ml
Copper Electrode Volume:-----	1.14 ml
<u>The volume of liquid to be measured:-----</u>	<u>56.8 ml</u>

Weights for 22 °C:	Water : 56.8 X 0.997768	= 56.67 g
	HX : 56.8 X 1.056	= 60.00 g

3 Conductive Copper Electrodes: (Pure Copper)

- i. Diameter : 6 mm
- ii. Total Height: 148 mm
- iii. Weight : 36 g
- iv. Copper electrodes inside of lower tubes: 40.27 mm
- v. Surface area of Copper Electrodes inside of lower tubes: 786.86 mm²
- vi. Copper electrodes inside of upper tubes: 52.8 mm
- vii. Surface area of Copper Electrodes inside of upper tubes: 1023.01 mm²

4 Target Room: Interior Wall Polycarbonate transparent pipe

- I. External Diameter : 16 mm
- II. Internal Diameter : 11.65 mm
- III. Height : 192.5 mm
- IV. Total Volume : 20.50 ml
- V. Liquid Volume : 16.035 ml
- VI. Liquid weight (Water) 16 g**
- VII. Liquid Level: 162.6 mm

5 Sensors:

- I. Visual Sensors; diameter 4 mm, height 35 mm, K type thermocouple
- II. Data logger sensors; diameter 4 mm, height 35 mm, J type thermocouple
- III. Total volume inside of the liquid: 0.188 ml
- IV. Sensors calibrated between 20°C and 90°C

6 Isolated Air Gap:

There is a 5 mm air gap between inner wall and outer wall.
Sensor holders and partitions touch outer pipes with 2mm surface area.

7 Outer Isolation Wall

Outside effect minimized by using outer wall which is 30 mm (external diameter) and 26 mm (internal diameter) polycarbonate transparent pipe and heat losses minimized.

Appendix- B: Sample of Heat Transfer Heat Transfer Calculation as Supplied by KODEM Ltd:**Heat Transfer Calculation**

The difference in total energy transferred to the heat sinks up to and including the steady state period can be clearly understood by considering the sensible heat gained by the heat sinks using the equation ($Q = m C_p \Delta T$) for each fluid up to the period of 3870 second (i.e. end of heating and steady state cycle).

Heat Transfer Water to Water

End Temperature: 33.62 °C

Starting Temperature: 17.37 °C

Temperature Difference: 16.25 (K)

$$Q = 0.016 \text{ kg} \times 4.187 \text{ kJ/kgK} \times 16.25 \text{ K} = 1088.6 \text{ J}$$

Heat Transfer Hydromx to Water

End Temperature: 39.73 °C

Starting Temperature: 17.40 °C

Temperature Difference: 22.33 (K)

$$Q = 0.016 \text{ kg} \times 4.187 \text{ kJ/kgK} \times 22.3 \text{ K} = 1495.9 \text{ J}$$

This equates to 37% increase in energy transferred up to the end of the steady state period.