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Experimental Investigation of Impact of Working Fluid and Pipe Material on Heat Pipe Performance

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Abstract. A passive device, the heat pipe has the capacity to transfer massive volumes of heat over small cross-sectional areas at extremely small temperature differentials heat pipes are extensively employed in many engineering applications owing to their exceptional efficiency in heat transfer, enabling the transmission of heat over considerable distances while minimizing temperature fluctuations. It is a heat transmission technique that is becoming more and more useful. The fundamental design of a heat pipe consists of an empty chamber placed after a cylinder or square filled with a vaporizable working fluid. This technique of heat transfer is used in solar water heaters, computers, solar power boards, laptops, mobile devices, and electronic circuits. Devices that require a large volume of heat transformations and heat management greatly benefit from the usage of heat pipes. This study investigates the influence of working fluid and pipe material on the performance of heat pipes. The researchers developed a complete experimental configuration to examine the performance attributes of heat pipes, encompassing thermal conductivity, heat transfer coefficient, and overall efficiency. The study examined a range of working fluids, including water, aceton, and ethnol, as well as different pipe materials such as copper, aluminium, and brass. The findings demonstrate notable disparities in performance indicators depending on the selection of the working fluid and pipe material. The entire heat transfer capability is significantly influenced by the thermal conductivity of the working fluid, whereby specific fluids demonstrate higher performance compared to others. The heat transfer efficiency is significantly influenced by the thermal conductivity and surface characteristics of the pipe material. Furthermore, the compatibility between the working fluid and pipe material significantly influences the long-term reliability and durability of heat pipes. Corrosion, material degradation, and phase change characteristics are critical factors that must be carefully considered when selecting the optimal combination of working fluid and pipe material. This study provides valuable insights into the design and optimization of heat pipes for various thermal management applications, highlighting the importance of selecting appropriate working fluids and pipe materials to enhance performance and reliability.

Keywords: heat pipes, thermal conductivity, heat transfer coefficient, overall efficiency

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Экспериментальное исследование влияния рабочей жидкости и материала трубы на характеристики тепловых труб

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Реферат. Тепловая труба, являясь пассивным устройством, способна передавать огромные объемы теплоты при малых площадях поперечного сечения чрезвычайно малых перепадах температур. Благодаря своей исключительной

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эффективности в передаче теплоты тепловые трубы широко используются во многих инженерных сооружениях, позволяя передавать теплоту на значительные расстояния, минимизируя при этом колебания температуры. Этот метод передачи теплоты становится все более и более востребованным. В основе конструкции лежит пустая камера, расположенная после цилиндра или квадрата, заполненного испаряющейся рабочей жидкостью. Данный метод теплопередачи используется в солнечных водонагревателях, компьютерах, солнечных энергосборниках, ноутбуках, мобильных устройствах и электронных схемах. Использование тепловых труб значительно повышает эффективность устройств, требующих больших объемов теплопередачи и эффективного управления тепловыми процессами. В данной работе изучается влияние рабочей жидкости и материала на характеристики тепловых труб. Авторы разработали полноценную экспериментальную установку для изучения характеристик тепловых труб, включая теплопроводность, коэффициент теплопередачи и общую эффективность. В процессе исследований был изучен ряд рабочих жидкостей, включая воду, ацетон и этанол, а также различные материалы труб, такие как медь, алюминий и латунь. Полученные результаты демонстрируют существенные различия в показателях производительности в зависимости от выбора рабочей жидкости и материала трубы. В целом теплопередающая способность в значительной степени зависит от теплопроводности рабочей жидкости, при этом определенные жидкости имеют более высокие показатели по сравнению с другими. Эффективность теплопередачи в значительной степени зависит от теплопроводности и характеристик поверхности материала трубы. Кроме того, совместимость рабочей жидкости и материала трубы существенно влияет на долговременную надежность и долговечность тепловых труб. Коррозия, деградация материала и фазовые переходы являются критически важными факторами, которые необходимо тщательно учитывать при выборе оптимального сочетания рабочей жидкости и материала трубы. Данное исследование предоставляет ценную информацию о проектировании и оптимизации тепловых труб для различных применений в области терморегулирования, подчеркивая важность выбора соответствующих рабочих жидкостей и материалов труб для повышения производительности и надежности.

Ключевые слова: тепловые трубы, теплопроводность, коэффициент теплопередачи, общая эффективность

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1. Introduction

The heat pipe is an active mechanism that induces a phase transition in the evaporator and condenser section when the working liquid is much higher than the wick material and adiabatic portion. A heat pipe is a sealed enclosure that facilitates the transmission of heat by means of a working fluid, encompassing an evaporator, adiabatic, and condenser region, from a heat source with a higher temperature to a heat sink with a lower temperature. Heat is transported from the working fluid at the evaporator area to the container of the evaporator chamber. At the condenser portion, it is released into nature, and the adiabatic passage does not move any heat. The evaporator, wick, and condenser are the three primary components of the heat pipe assembly [1]. The utilization of the working fluid is crucial for the efficient transfer of energy, facilitating the transmission of heat from the heat source to the condenser or cooling component, as well as enabling the distribution of power within the stream with little heat hindrance [2]. To grow and become exceptional, one must grasp the trend point. The wick's structure relates to the narrow property method for determining weights that, to the greatest extent practical, affect the activity instrument of the heat channel and joined capacity, such as entrainment, bubbling, and sonic, if they occur during the activity cycle. Managing heat has emerged as a critical difficulty in generating many breakthroughs [3]. Modern design always demands that strong components be small and light, from space sections to control devices. This leads to high heat transitions and significant challenges.

Heat pipes form a crucial component in several thermal management systems across a wide range of industries, from aerospace and electronics to energy and HVAC systems. These passive heat transfer devices offer outstanding efficiency in dispersing heat from hot regions to heat sinks or other cooling surfaces, making them indispensable in situations where thermal management is crucial. The performance of heat pipes, however, is governed by several elements, among which the choice of working fluid and pipe material stands out as crucial [4]. The working fluid within a heat pipe acts as the medium for heat transmission, undergoing phase transition processes to effectively transmit thermal energy. Different working fluids exhibit distinct thermophysical properties, including thermal conductivity, latent heat of vaporization, and viscosity, which directly effect the heat transfer characteristics of the heat pipe. Additionally, the selection of pipe material is equally critical, as it affects not only the structural integrity but also the thermal conductivity and compatibility with the working fluid. The relationship between working fluid and pipe material in determining the performance of heat pipes has been a subject of extensive research. Understanding how variations in these parameters influence heat transfer efficiency, thermal conductivity, and overall reliability is essential for optimizing the design and functionality of heat pipes across diverse applications [5, 6].

In this research paper, we delve into the intricate interplay between working fluid and pipe material and their combined effect on the performance of heat pipes. Through experimental analysis and theoretical modeling, we aim to elucidate the impact of different working fluids and pipe materials on key performance metrics such as thermal conductivity, heat transfer coefficient, and overall efficiency [7–9]. By systematically exploring various combinations of working fluids and pipe materials, we seek to provide valuable insights into the design principles and optimization strategies for enhancing the performance and reliability of heat pipes in real-world applications.

This research not only contributes to advancing the fundamental understanding of heat pipe operation but also offers practical guidelines for engineers and designers in selecting optimal working fluid-pipe material combinations tailored to specific thermal management requirements [10, 11]. Ultimately, this knowledge can pave the way for the development of more efficient and robust heat pipe systems capable of meeting the increasingly demanding thermal challenges posed by modern engineering applications. Researchers are always trying to figure out how to use heat pipes as high-proficiency latent methods for heat transmission in hardware, solar innovation, and aviation.

New working liquids were consolidated, and new wick architectures for regular and level heat pipes were suggested. The development of several circular heat pipe types widely used in contemporary applications–the research on both adjustable and miniature heat pipes. Novel uses were considered, like heat pipe-coordinated turbines and sun-based authority sections. The interaction between phase change materials and heat pipes was investigated for cooling applications [12–13]. The basic structure of a heat pipe is illustrated in Fig. 1.

A wick structure or wick is used to return the condensate to the vaporizing area once the working fluid has become dense and evaporated in another part of the heat pipe. The wick's pore size, porosity, and thermal conductivity, among other characteristics, determine how far the heat pipe can function. The difference between the wick structure's thin spans at the condenser end (RCC) and evaporator end (rce). It makes the wick submerged in fluid have a net weight contrast. The fluid exits the condenser by evaporation due to this weight differential.

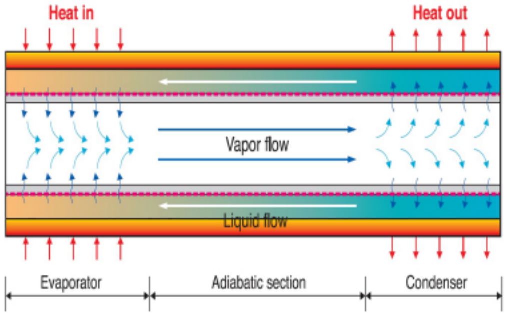

Fig. 1. Sketch of heat pipe [8]

The thermodynamic behavior and components of the heat pipe are shown in Fig. 2.

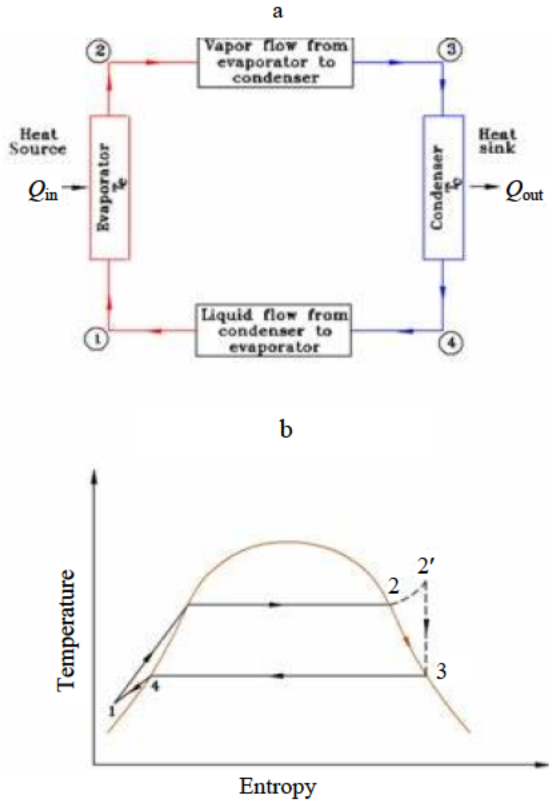

Fig. 2. Heat Pipe Thermodynamic Diagram [12]:
a – various components; b – temperature–entropy diagram

The thermophysical properties and compatibility of working fluids with pipe materials are presented in Table 1.

Table 1

The working fluid of heat pipe and Heat pipe container material and working fluid

Working Fluid	Melting Point, K at 1 atm	Boiling Point, K at 1 atm	Useful Range, K	Cooper	Aluminium	Brass
Water	273.1	373.1	303–550	✓	×	×
Acetone	180.0	329.4	273–393	✓	✓	✓
Ethanol	158.7	351.5	273–403	×	×	×

Literature Survey

Numerous studies evaluated heat pipes' characteristics and important variables using theoretical and experimental mathematical models. Garcia et al. examined the numerical solution for the laminar two-phase flow of liquid and vapour of working fluid in the capillary structure of microheat pipes. An examination of the link between the capillary pressure and the maximal heat transfer capacity is undertaken.The results are compared with data from the specialized literature to validate the mathematical models [1]. Based on the momentum conservation and Laplace-Young equations, an analytical formula for the minimum meniscus radius and a presentation of the maximum capillary heat transport limit in micro/small heat pipes were derived. Numerous studies have been created to generalize technologies in a certain field, identifying optimum working circumstances and likely downsides. The constraints and operating parameters have been acknowledged; however, the Technology has not been validated or certified for use in an industrial context. The resulting results are compared with data presented in the specialized literature to validate the mathematical models. Based on the momentum conservation and Laplace-Young equations, an analytical formula for the minimum meniscus radius and a presentation of the maximum capillary heat transport limit in micro/small heat pipes were derived. Numerous studies have been created to generalize technologies in a particular field, indicating ideal working conditions and probable drawbacks. Chan et al. looked into the numerous wick types and different heat pipes. Heat pipes have more than 20 years of lifespan and no moving parts. Manufacturing process control is the main factor influencing heat pipe reliability. The long-term performance of a heat pipe is measurably impacted by the seal of the line, the quality of the materials used in the wick structure, and the cleanliness of the internal chamber. Any leak will eventually cause the tube to stop working. Performance will gradually deteriorate due to NCG formation, facilitated by contamination of the wick structure and inner chamber. Robust testing and well-designed procedures are needed to guarantee heat pipes.

According to the survey, the most popular uses for oscillating and rotating heat pipes are in low-temperature heat pipes and engine coolant systems, among other applications. The total results offer countless opportunities; however, there is a problem with the lack of confirmation surrounding these subjects, particularly with the development of hybrid Technology.

Cryogenic heat pipes highlighting the problems with closed-loop heat pipes (CLHP) and the system's unavailability. The evaluation recommends tactics that consider supercritical startup while optimizing each CLHP system's performance. Technological advancements like nanofluids increase the complications because of the metallic particles. Heat pipes and nanofluids are relatively new technologies, and more and more trials and validations exist. Heat pipes have many uses, from low temperatures to nuclear power. However, the extant literature highlights the absence of advancement towards an industrial implementation. Sameer Khandeker and Manfred Groll published an international study on pulsing heat pipes. According to them, pulsating heat pipes, or PHPs, have become fascinating substitutes for traditional heat transmission systems. These seemingly straightforward devices have magnetic thermohydrodynamic operating.

The thermal performance of heat pipes employing various working fluids, including water, ammonia, and refrigerants. The researchers conducted experiments to analyze heat transfer characteristics such as thermal conductivity and heat transfer coefficient. They found significant variations in performance metrics depending on the choice of working fluid, highlighting the importance of fluid selection in heat pipe design.

The influence of pipe material on the thermal conductivity of heat pipes. Through experimental investigations using different pipe materials such as copper, aluminium, and stainless steel, they observed variations in thermal conductivity and heat transfer efficiency. Their findings underscore the importance of considering pipe material in optimizing heat pipe performance.

Conduct a comparison study to evaluate the performance of heat pipes using different combinations of working fluids and pipe materials. By researching thermal conductivity, heat transfer coefficient, and compatibility concerns, they provide insights into the synergistic impacts between working fluid and pipe material on heat pipe performance. Their research helps to a better understanding of the intricate interactions regulating heat pipe behavior. The impact of corrosion on the performance of heat pipes utilizing different working fluids and pipe materials. Through accelerated aging tests and corrosion analysis, they elucidate the degradation mechanisms and reliability issues associated with specific fluid-material combinations. Their findings emphasize the importance of considering corrosion resistance when selecting working fluids and pipe materials for long-term heat pipe applications.

The optimization framework for heat pipe design considering the combined effects of working fluid and pipe material. By employing computational modeling and multi-objective optimization techniques, they identify optimal fluid-material combinations that maximize heat transfer efficiency while minimizing material degradation and compatibility issues. Their research provides valuable insights into the holistic design approach for enhancing heat pipe performance.

Overall, the reviewed literature underscores the significance of considering both working fluid and pipe material in the design and optimization of heat pipes. While each parameter independently influences heat pipe performance, their combined effect presents a complex interplay that necessitates careful consideration to achieve optimal thermal management solutions.

Experimental Setup

In our research paper concentrating on the experimental investigation of the influence of working fluid and pipe material on the performance of heat pipes, a rigorous experimental setup was designed to enable reliable data collection and analysis. The setup was designed to systematically adjust both the working fluid and the pipe material while monitoring important performance characteristics such as thermal conductivity, heat transfer coefficient, and overall efficiency

1. Heat Pipe Assembly

The heart of the experimental setup consisted of a series of heat pipes, each carefully constructed to maintain consistency and repeatability throughout the experiments. The heat pipes were fabricated using different pipe materials including copper, aluminium, and stainless steel, each with precise dimensions and surface finishes to minimize variations. Uniformity in heat pipe construction was maintained to ensure that any observed differences in performance could be attributed solely to variations in working fluid and pipe material.

2. Working Fluid Selection

A variety of working fluids were considered for experimentation, including water, ammonia, and various refrigerants commonly used in heat pipe applications. Each working fluid was carefully selected based on its thermophysical properties such as thermal conductivity, latent heat of vaporization, and compatibility with the chosen pipe materials. The purity and consistency of each working fluid were verified to eliminate any extraneous factors that could influence experimental results.

3. Thermal Testing Setup

A controlled thermal testing environment was established to simulate real-world operating conditions for the heat pipes. Heat sources and sinks were carefully controlled to maintain stable temperature differentials across the heat pipes. Temperature sensors were strategically placed along the length of the heat pipes to monitor temperature gradients and ensure uniform heat transfer. Heat transfer fluid circulation loops were employed to maintain consistent operating conditions throughout the experimental trials. The experimental setup developed for the present investigation is shown in Fig. 3.

Fig. 3. Experimental setup

Observation Table

The observations obtained during free convection experiments are summarized in Table 2.

Table 2

Free Convection
Time Duration 10 Minute

Sr. No	Inlet Temp. C	Outlet Temp. C	Type of Fluid	Pipe Material	Source Distance in cm	Pipe Diameter in mm
1	61	36.8	Water	Copper	2.5	6
2	60	37.5	Water	Copper	5.0	6
3	56.5	37.5	Water	Copper	7.5	6
4	49.8	36.2	Water	Copper	10.0	6
5	58.5	37.4	Acetone	Aluminium	2.5	8
6	63.1	38.6	Acetone	Aluminium	5.0	8
7	63.5	38.6	Acetone	Aluminium	7.5	8
8	53.9	37.1	Acetone	Aluminium	10.0	8
9	72.5	37.9	Acetone	Copper	2.5	6
10	70.8	38.1	Acetone	Copper	5.0	6
11	58.1	34.4	Acetone	Copper	7.5	6
12	53.4	34.7	Acetone	Copper	10.0	6
13	73.5	39.8	Water	Copper	2.5	8
14	65.8	39.3	Water	Copper	5.0	8
15	61.9	38.3	Water	Copper	7.5	8
16	55.8	37.1	Water	Copper	10.0	8
17	77.1	38.5	Water	Aluminium	2.5	6
18	69.8	37.9	Water	Aluminium	5.0	6
19	56.8	36.2	Water	Aluminium	7.5	6
20	52.6	35.6	Water	Aluminium	10.0	6
21	66.6	40.3	Ethanol	Copper	2.5	8
22	65.1	39.2	Ethanol	Copper	5.0	8
23	57.1	38.1	Ethanol	Copper	7.5	8
24	54.3	36.5	Ethanol	Copper	10.0	8
25	64.5	38.3	Ethanol	Copper	2.5	6
26	63.7	36.2	Ethanol	Copper	5.0	6
27	58.6	36.2	Ethanol	Copper	7.5	6
28	58.3	36.1	Ethanol	Copper	10.0	6
29	67.3	36.6	Ethanol	Aluminium	2.5	6
30	66.4	38.1	Ethanol	Aluminium	5.0	6
31	63.4	37.1	Ethanol	Aluminium	7.5	6
32	59.1	36.6	Ethanol	Aluminium	10.0	6
33	66.9	34.9	Water	Brass	2.5	8
34	65.4	35.2	Water	Brass	5.0	8

The experimental observations for forced convection are presented in Table 3.

Table 3

Forced Convection
Time Duration 10 Minute

Sr. No	Inlet Temp in C	Outlet Temp in C	Type of Fluid	Pipe Material	Source Dist.	Pipe diameter
1	52.2	32.4	Water	Copper	2.5	6
2	50.1	33.5	Water	Copper	5.0	6
3	44.8	33.6	Water	Copper	7.5	6
4	42.1	33.2	Water	Copper	10.0	6
5	50.9	33.2	Acetone	Aluminium	2.5	8
6	48.9	33.1	Acetone	Aluminium	5.0	8
7	45.9	33.0	Acetone	Aluminium	7.5	8
8	42.5	33.1	Acetone	Aluminium	10.0	8
9	49.4	33.1	Acetone	Copper	2.5	6
10	45.3	33.1	Acetone	Copper	5.0	6
11	43.6	32.5	Acetone	Copper	7.5	6
12	41.2	32.8	Acetone	Copper	10.0	6
13	60.5	34.0	Water	Copper	2.5	8
14	55.4	34.0	Water	Copper	5.0	8
15	50.4	33.7	Water	Copper	7.5	8
16	47.1	33.6	Water	Copper	10.0	8
17	48.6	33.2	Water	Aluminium	2.5	6
18	44.3	33.3	Water	Aluminium	5.0	6
19	41.4	32.3	Water	Aluminium	7.5	6
20	38.1	32.5	Water	Aluminium	10.0	6
21	66.5	34.6	Acetone	Copper	2.5	8
22	59.1	34.3	Acetone	Copper	5.0	8
23	52.5	33.9	Ethanol	Copper	7.5	8
24	49.7	33.9	Ethanol	Copper	10.0	8
25	53.9	33.1	Ethanol	Copper	2.5	6
26	50.9	33.3	Ethanol	Copper	5.0	6
27	45.8	33.4	Ethanol	Copper	7.5	6
28	44.9	33.6	Ethanol	Copper	10.0	6
29	56.8	33.7	Ethanol	Aluminium	2.5	6
30	52.4	33.8	Ethanol	Aluminium	5.0	6
31	47.9	33.3	Ethanol	Aluminium	7.5	6
32	45.5	33.6	Ethanol	Aluminium	10.0	6
33	50.1	33.4	Water	Brass	2.5	8
34	47.5	33.5	Water	Brass	5.0	8
35	44.5	33.5	Water	Brass	7.5	8
36	43.1	33.6	Water	Brass	10.0	8
37	59.6	31.5	Acetone	Aluminium	2.5	6
38	53.9	31.8	Acetone	Aluminium	5.0	6
39	47.2	32.0	Acetone	Aluminium	7.5	6
40	46.5	32.5	Acetone	Aluminium	10.0	6
41	57.4	31.9	Ethanol	Brass	2.5	8

End of Table 3

Sr. No	Inlet Temp in C	Outlet Temp in C	Type of Fluid	Pipe Material	Source Dist.	Pipe diameter
42	53.6	32.0	Ethanol	Brass	5.0	8
43	50.4	31.8	Ethanol	Brass	7.5	8
44	45.9	31.6	Ethanol	Brass	10.0	8
45	50.3	33.0	Acetone	Copper	2.5	8
46	46.4	33.0	Acetone	Copper	5.0	8
47	43.1	32.9	Acetone	Copper	7.5	8
48	40.7	32.8	Acetone	Copper	10.0	8
49	50.2	32.1	Ethanol	Aluminium	2.5	8
50	45.3	32.0	Ethanol	Aluminium	5.0	8
51	42.5	32.0	Ethanol	Aluminium	7.5	8
52	38.5	32.1	Ethanol	Aluminium	10.0	8
53	53.8	32.3	Water	Aluminium	2.5	8
54	48.9	32.2	Water	Aluminium	5.0	8
55	44.8	32.1	Water	Aluminium	7.5	8
56	42.8	32.4	Water	Aluminium	10.0	8
57	57.3	31.5	Ethanol	Brass	2.5	8
58	54.0	31.6	Ethanol	Brass	5.0	8
59	49.6	31.9	Ethanol	Brass	7.5	8
60	46.9	32.1	Ethanol	Brass	10.0	8
61	49.3	32.1	Acetone	Brass	2.5	8
62	47.7	32.1	Acetone	Brass	5.0	8
63	45.8	32.0	Acetone	Brass	7.5	8
64	42.8	32.1	Acetone	Brass	10.0	8

Sample Calculations

(a) Free convection

Fixed parameter:

Room\Reference temperature = 31.3 °C
Length of the pipe = 300 mm
Wick material = Bandage (Cotton)
Q = convective = [Ha(ΔT)]
A = Curved surface area of pipe
h = convective heat transfer coefficient
h (for free convection) = 10 W/(m^2· K)

1 READING. $\Delta T = [61.0 - 36.8]$
…
5READING. $\Delta T = [58.5 - 37.4] = 21.1$ °C
$Q = 10\pi \cdot 0.006 \cdot 0.3 \cdot (27.5)$
…
$Q = 10\pi \cdot 0.008 \cdot 0.3 \cdot (21.1)$
$Q = 1.49$ watt…
$Q = 1.58$ watt…

2 READING. $\Delta T = [60.0 - 37.5] = 27.5$ °C
…
6 READING. $\Delta T = [63.1 - 38.6] = 24.9$ °C
$Q = 10\pi \cdot 0.006 \cdot 0.3 \cdot (27.5)$
$Q = 10\pi \cdot 0.008 \cdot 0.3 \cdot (24.9)$
$Q = 1.49$ watt…
$Q = 1.84$ watt…

(b) Forced convection:

Room\Reference temperature = 31.3 °C
Length of the pipe = 300 mm
Wick material = Bandage (Cotton)

Formula used

Type of heat transfer is forced convection

Q = convective = [Ha(ΔT)]
A = Curved surface area of pipe
h = convective heat transfer coefficient
havg (for forced convection) = 200 W/(m^2·K)

1 READING. $\Delta T = [52.3 - 32.4]$
…
5 READING. $\Delta T = [50.9 - 33.2] = 15.8$ °C
$Q = 200\pi \cdot 0.006 \cdot 0.3 \cdot (19.8)$
…
$Q = 200\pi \cdot 0.008 \cdot 0.3 \cdot (15.8)$
$Q = 22.3$ watt…
$Q = 26.67$ watt…

2 READING. $\Delta T = [44.8 - 33.6] = 27.5$ °C
6 READING. $\Delta T = [48.9 - 33.1] = 12.9$ °C
$Q = 200\pi \cdot 0.006 \cdot 0.3 \cdot (27.5)$
$Q = 200\pi \cdot 0.008 \cdot 0.3 \cdot (12.9)$
$Q = 18.76$ watt…
$Q = 23.81$ watt…

Result Table:

The calculated results for water as the working fluid are shown in Table 4.

The performance results using ethanol as the working fluid are summarized in Table 5.

The experimental results obtained using acetone as the working fluid are presented in Table 6.

Table 4

Fluid Used-Water

Sr. No	Temperature difference (C)	Heat Rejected (W)	Time (min)	Pipe Material	Source Distance (cm)	Pipe diameter (mm)
1	21.5	16.2	10	Aluminium	2.5	8
2	16.7	25.17	10	Aluminium	5	8
3	12.7	19.14	10	Aluminium	7.5	8
4	10.4	15.67	10	Aluminium	10	8
5	15.4	17.4	10	Aluminium	2.5	6
6	11	12.43	10	Aluminium	5	6
7	9.1	10.2	10	Aluminium	7.5	6
8	5.6	6.33	10	Aluminium	10	6
9	26.5	39.95	10	Copper	2.5	8
10	21.4	32.25	10	Copper	5	8
11	16.7	25.17	10	Copper	7.5	8
12	14.1	21.25	10	Copper	10	8
13	19.8	22.3	10	Copper	2.5	6
14	16.6	18.76	10	Copper	5	6
15	11.2	12.66	10	Copper	7.5	6
16	8.9	10.06	10	Copper	10	6
17	16.7	25.05	10	Brass	2.5	8
18	14	21	10	Brass	5	8
19	11	16.5	10	Brass	7.5	8
20	9.5	14.25	10	Brass	10	8

Table 5

Fluid Used: Ethanol

Sr. No	Temperature difference (C)	Heat Rejected (W)	Time (min)	Pipe Material	Source Distance (cm)	Pipe diameter (mm)
1	2	3	4	5	6	7
21	18.1	13.6	10	Aluminium	2.5	8
22	13.3	10.02	10	Aluminium	5	8
23	10.5	7.91	10	Aluminium	7.5	8
24	6.4	48.2	10	Aluminium	10	8
25	23.1	26.103	10	Aluminium	2.5	6
26	18.6	21.018	10	Aluminium	5	6
27	14.6	16.498	10	Aluminium	7.5	6
28	11.9	13.447	10	Aluminium	10	6
29	31.6	47.85	10	Copper	2.5	8
30	24.8	37.2	10	Copper	5	8
31	18.6	27.9	10	Copper	7.5	8
32	15.8	23.7	10	Copper	10	8
33	20.8	23.54	10	Copper	2.5	6
34	17.6	19.88	10	Copper	5	6
35	12.4	14.012	10	Copper	7.5	6
36	11.3	12.769	10	Copper	10	6
37	25.5	19.21	10	Brass	2.5	8
38	21.6	16.27	10	Brass	5	8
39	18.6	14.01	10	Brass	7.5	8
40	14.3	10.77	10	Brass	10	8

Table 6

Fluid Used: Acetone

Sr. No	Temperature difference (C)	Heat Rejected (W)	Time (min)	Pipe Material	Source Distance (cm)	Pipe diameter (mm)
41	17.7	26.67	10	Aluminium	2.5	8
42	15.8	23.81	10	Aluminium	5	8
43	12.9	19.44	10	Aluminium	7.5	8
44	9.4	14.16	10	Aluminium	10	8
45	27.9	31.53	10	Aluminium	2.5	6
46	22.1	24.98	10	Aluminium	5	6
47	15.2	17.18	10	Aluminium	7.5	6
48	14	15.82	10	Aluminium	10	6
49	17.3	13.03	10	Copper	2.5	8
50	13.4	10.09	10	Copper	5	8
51	10.2	7.68	10	Copper	7.5	8
52	7.9	35	10	Copper	10	8
53	16.3	24.56	10	Copper	2.5	6
54	12.2	18.38	10	Copper	5	6
55	11.1	16.72	10	Copper	7.5	6
56	8.4	12.66	10	Copper	10	6
57	17.2	25.9	10	Brass	2.5	8
58	15.6	23.51	10	Brass	5	8
59	13.8	20.79	10	Brass	7.5	8
60	10.7	16.12	10	Brass	10	8

Result and Discussion

The temperature variation for different aluminium heat pipe configurations is presented in Fig. 4.

The temperature variation for different copper heat pipe configurations is illustrated in Fig. 5

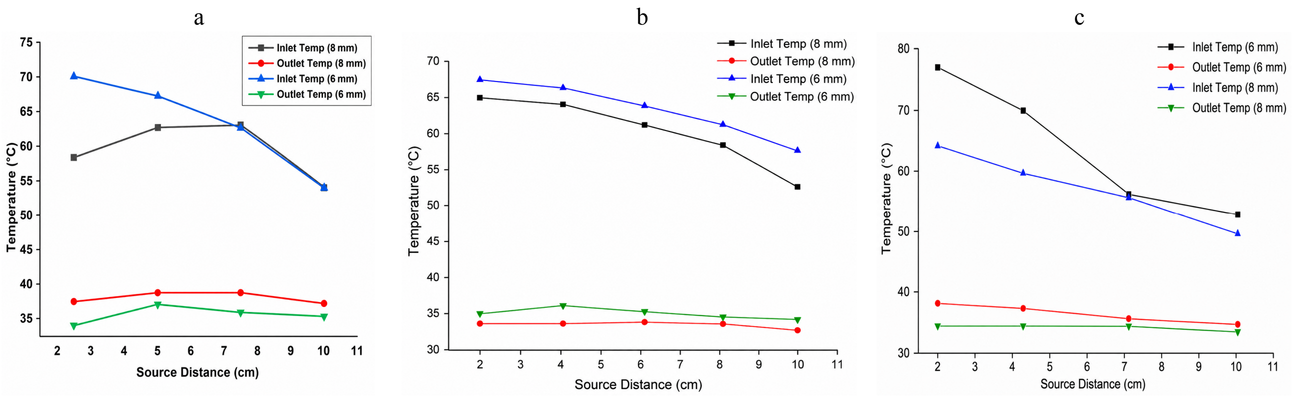

Fig. 4. a – Acetone-Aluminium; b – Ethanol-Aluminium; c – water-Aluminium

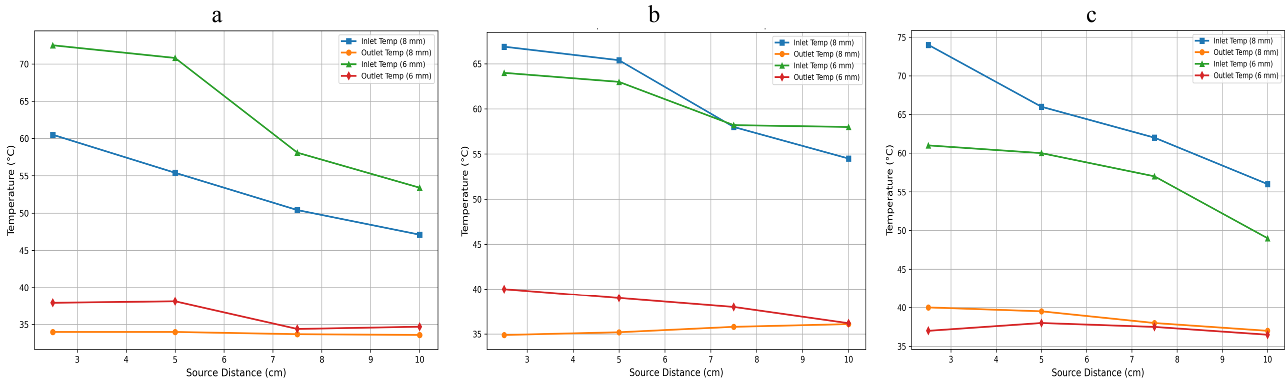

Fig. 5. a – Acetone-Copper; b – Ethanol-Copper; c – water-Copper

CONCLUSION

This research paper has provided vital insights into the major impact of working fluid and pipe material on the performance of heat pipes. Through thorough experimentation and analysis, it has been established that the choice of working fluid and pipe material plays a key role in determining the efficiency and efficacy of heat pipes in heat transfer applications. The findings of this study underline the need of carefully selecting the proper working fluid and pipe material based on specific operating conditions and intended performance goals. Different combinations of working fluids and pipe materials exhibit varying thermal conductivity, heat transfer rates, and overall performance characteristics, highlighting the need for tailored solutions in different contexts Furthermore, this research contributes to the broader understanding of heat pipe technology, offering valuable guidance for engineers, researchers, and practitioners in optimizing heat transfer systems for diverse applications. By leveraging the insights gained from this study, future advancements in heat pipe technology can be pursued, leading to enhanced efficiency, sustainability, and reliability in thermal management systems.

Three different pipe types–brass, aluminium, and copper–with varying diameters are used in this investigation. Brass has an 8mm diameter, aluminium has two diameters of 6 and 8 mm, and copper has two diameters of 6 and 8 mm. Ethanol, distilled water, and acetone are the three working fluids; cotton is a weak material for partial pressure drops. For every combination – 2.5, 5, 7.5, and 10 cm – the distance between the source and the aluminium plate varied.

The highest temperature difference and heat rejection for free convection is obtained for aluminium pipe of 6 mm diameter and using as a fluid, result obtained were 38.5 °C and 2.17 W. An 8 mm copper pipe allows for a maximum temperature differential of approximately 26.3 °C and a maximum heat transfer of around (19.8 W). These two readings provide better heat rejection for convection-type heat transmission.

Overall, this research underscores the importance of considering the interplay between working fluid and pipe material in designing and optimizing heat pipe systems, paving the way for more efficient and effective heat transfer solutions in various industrial and technological domains.

Future Scope:

- Advanced Materials Exploration: Investigate the use of novel materials, such as graphene-based composites or nanomaterial-enhanced surfaces, for heat pipe construction.
- Explore the potential of additive manufacturing techniques to fabricate heat pipes with complex geometries and optimized thermal properties.
- Multi-Phase Working Fluids: Conduct experiments with multi-phase working fluids, such as nanofluids or hybrid mixtures, to enhance heat transfer performance and operating range. Investigate the influence of phase change phenomena, such as boiling and condensation, on heat pipe behavior and efficiency.
- Enhanced Performance under Extreme Conditions: Study the performance of heat pipes under extreme operating conditions, including high temperature differentials, vacuum environments, and microgravity conditions.
- Explore innovative heat pipe designs and materials to withstand harsh environments encoun-

tered in space exploration and aerospace applications. Optimization of Operational Parameters:

- Conduct parametric studies to optimize operational parameters such as working fluid fill ratio, pipe diameter, and inclination angle for maximum heat transfer efficiency.
- Microscale Heat Pipe Research: Explore the feasibility of microscale heat pipes for compact thermal management solutions in electronics cooling and microfluidic devices.
- Environmental Considerations: Investigate the environmental impact of different working fluids and pipe materials used in heat pipe construction. Explore eco-friendly alternatives and sustainable manufacturing processes to minimize the carbon footprint of heat pipe technologies.
- Investigate corrosion resistance, material fatigue, and thermal cycling effects to enhance the durability of heat pipe systems.

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