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Fabrication of Heat Storage Unit Using PCM

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Abstract: The project titled "Fabrication of Heat Storage Unit Using PCM" aims to explore the feasibility and effectiveness of utilizing Phase Change Materials (PCM) for thermal energy storage. Thermal energy storage plays a crucial role in various applications, including solar energy systems, building heating and cooling, and industrial processes. This report presents the fabrication process of a heat storage unit utilizing PCM and evaluates its thermal performance. The project involved the selection of suitable PCM, fabrication of the heat storage unit, and experimental testing to measure its heat storage capacity and thermal performance. Results indicate that the fabricated heat storage unit effectively stores and releases thermal energy, demonstrating its potential for practical applications in energy-efficient systems. The findings contribute to the advancement of thermal energy storage technology and provide insights for future research and development in this field. The use of a latent heat storage system using phase change materials is an effective way of storing thermal energy. In this project a PCM based tube in shell heat exchanger is designed and fabricated. The project focuses on the temperature distribution pattern of the phase change material during the process of charging and discharging the results are obtained by experimentally. Paraffin wax has been used as the phase change material. This type of thermal energy storage system can be used as a medium to store energy and can be used further.

Keywords: Phase Change Material (PCM), Heat Storage, HTF, Paraffin Wax.

I. INTRODUCTION

1.1 Thermal Energy Storage (TES):

Electricity generation can release a large amount of heat that can be stored and utilized further for cooling, heating, and other applications, which would require efficient method of TES. As in case of the Combined Heat and Power (CHP) Plants, the heat released can be extracted using heat recovery units. This process is also known as cogeneration. Heat recovery units are utilized to extract heat from the hot exhaust gases, released from combustion of fuel to run turbines or engines. This heat can then be used for heating or cooling purposes in buildings or facilities. The heat released from the cogeneration process can be stored using various modes or methods of Thermal Energy Storage (TES). The principle of all TES applications is the same, i.e. thermal energy is supplied to storage media for periodic usage and heat extraction. The main difference arises in the scale and method of storage media. TES refers to storage of energy for certain period and its subsequent usage. Applications for this technology can be found in diverse disciplines like cogeneration, Solar Power, HVAC systems, and others. With the appropriate TES system, diurnal or seasonal storage and utilization of energy is possible. This means that, in areas where heating in winter or cooling in summer is required, it is possible to store heat during the summer and utilize it in the winter, and vice-versa for cooling in summer. This method would be targeted at a large time scale across months. Similar TES methods can be used for daily heating requirements at a smaller scale.

1.2 Methods of Thermal Energy Storage (TES):

Thermal energy can be stored using several media which focus on various methods of storage. TES is mainly classified into sensible, latent, and chemical energy storage, some of which have been discussed here.

1.2.1 Sensible Heat Storage: Sensible Heat is the energy released by a material as its temperature is reduced, or absorbed by a material as its temperature is increased, and this method of TES is called the Sensible Heat Storage. The effectiveness of Sensible Heat Storage depends on the specific heat of the storage material and, if volume is important, on its density. Sensible storage systems commonly use materials like rocks, ground, or water as the storage medium, and the thermal energy is stored by increasing the storage-medium temperature [1].

1.2.2 Latent Heat Storage: Latent heat storage materials are substances that can store and release large amounts of energy during phase transitions, such as melting or solidification, without a significant change in temperature. They are widely used for thermal energy storage, particularly in applications where maintaining a constant temperature is crucial. Some common types of latent heat storage materials include:

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Phase Change Materials (PCMs): PCMs are one of the most widely used latent heat storage materials. They can store and release thermal energy during the phase transition between solid and liquid states. Some commonly used PCMs include paraffin wax, fatty acids, organic compounds, and salt hydrates. These materials find applications in various fields, including building temperature regulation, solar energy storage, and thermal management systems.

II. LITERATURE REVIEW

Material Selection and Characterization: Studies have investigated a wide range of PCM materials including organic, inorganic, and bio-based compounds to identify suitable candidates based on their thermal properties, cost-effectiveness, and environmental impact. Research has focused on characterizing the thermal properties of PCMs such as latent heat of fusion, melting point, thermal conductivity, and stability over multiple cycles of charging and discharging.

Encapsulation Techniques: Various encapsulation methods have been explored to contain PCMs within suitable matrices or containers, preventing leakage and facilitating their integration into energy storage systems. Microencapsulation techniques such as spray drying, coacervation, and in situ polymerization have been investigated to encapsulate PCM particles within microcapsules with controlled morphology and size distribution. Microencapsulation methods involve embedding PCM within containers or matrices made from polymers, metals, ceramics, or composites to enhance mechanical strength and thermal stability.

Thermal Performance Evaluation: Studies have focused on evaluating the thermal performance of PCM-based energy storage devices under different operating conditions, including charging/discharging rates, temperature gradients, and cycling stability. Experimental techniques such as differential scanning calorimetry (DSC), thermal cycling tests, and transient heat transfer measurements have been employed to characterize the phase change behavior, heat storage capacity, and thermal conductivity of PCM systems.

Numerical Modeling and Simulation: Computational modeling and simulation have been used to predict the thermal behavior and performance of PCM-based energy storage devices, aiding in the design optimization and performance prediction. Finite element analysis (FEA), computational fluid dynamics (CFD), and mathematical modeling techniques have been applied to simulate heat transfer processes, phase change phenomena, and thermal energy storage dynamics within PCM systems.

Integration into Energy Systems: PCM-based energy storage devices have been integrated into various applications including buildings, vehicles, renewable energy systems, and electronic devices. Studies have explored the feasibility and effectiveness of PCM integration for passive building cooling/heating, thermal energy storage in concentrated solar power plants, battery thermal management in electric vehicles, and waste heat recovery in industrial processes.

Challenges and Future Directions: Despite the promising potential of PCM-based energy storage devices, several challenges remain to be addressed including cost-effectiveness, scalability, compatibility with existing infrastructure, and long-term stability. Future research directions may include the development of novel PCM materials with enhanced thermal properties, optimization of encapsulation techniques for improved efficiency and reliability, and integration into emerging energy storage technologies such as grid-scale systems and wearable electronics.

Cost and Availability: Consider the cost-effectiveness and availability of the PCM, especially for large-scale applications.

Compatibility: Ensure compatibility with encapsulation materials and other components of the energy storage system.

III. EXPERIMENTAL SETUP

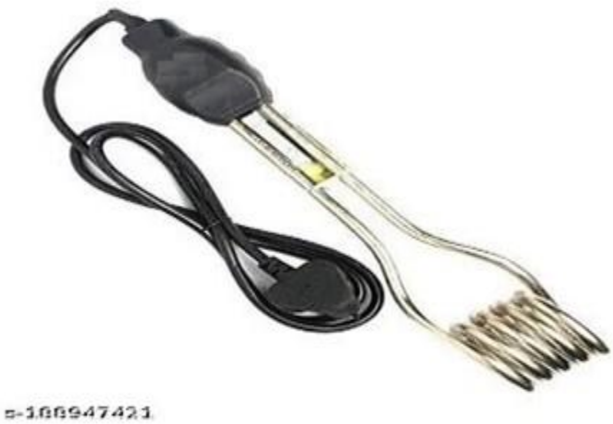
3.1 Components of Test Rig:

Energy storage unit: The energy storage unit is the main component of the test rig. The heat transfer fluid flows from the inner copper pipe. The outer pipe is of copper pipe, which also acts as insulating material. It prevents the melted wax to solidify after charging. The paraffin wax is incorporated in the outer pipe of the energy storage unit.

Storage Tank: The purpose of the storage tank is to act as a reservoir of water which will be circulated in the circuit. Ideally the storage tank should be insulated to prevent any exchange of heat through it.

Oil Pump: Dowty gear pumps are a type of hydraulic pump designed and manufactured by Dowty, a British engineering company known for its expertise in hydraulic systems and components. Gear pumps are widely used in hydraulic systems due to their simplicity, reliability, and efficiency. The purpose of the pump is to create a circulation in the circuit. The pump used in the circuit is a non-submersible fuel pump with a head of 6 feet.

Heating Coil: The purpose of the heating coil is to heat the water in the storage tank. The heating coil used in the setup is of 1500 W rating. Water heater coils are critical components in heating systems used to raise the temperature of water for various applications, from household use to industrial processes. In our project the heating coil is used to increase the temperature of oil in oil storage tank. The coil used in this project acts as Solar energy, thus showing the heat energy liberated such as Solar energy.



Diaphragm Control Valve: The purpose of flow control valve is to regulate the mass flow rate of the heat transfer fluid through the circuit. These valves use a flexible diaphragm to control flow. They are often used in applications where contamination must be minimized, such as in pharmaceutical or food processing.

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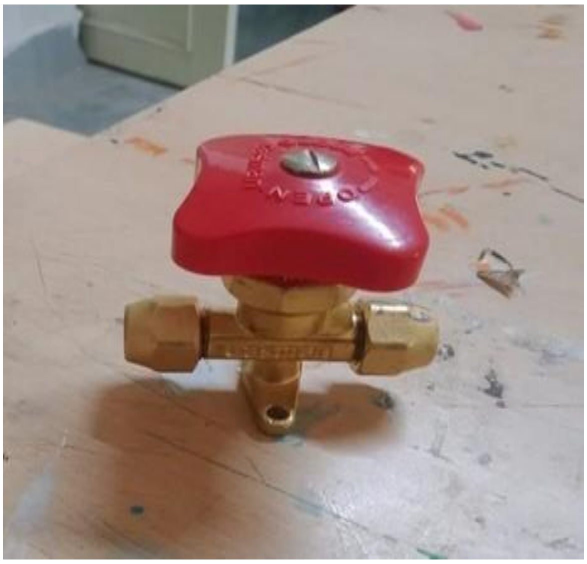
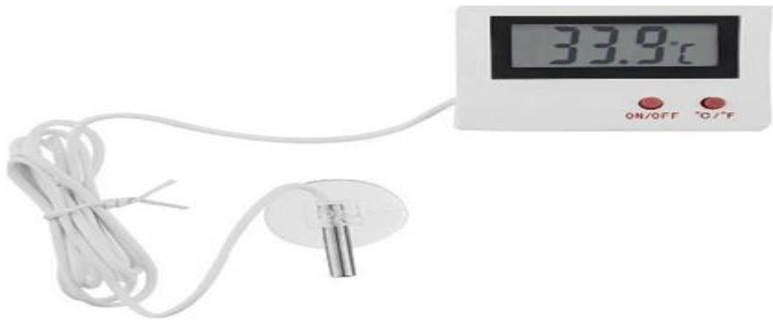
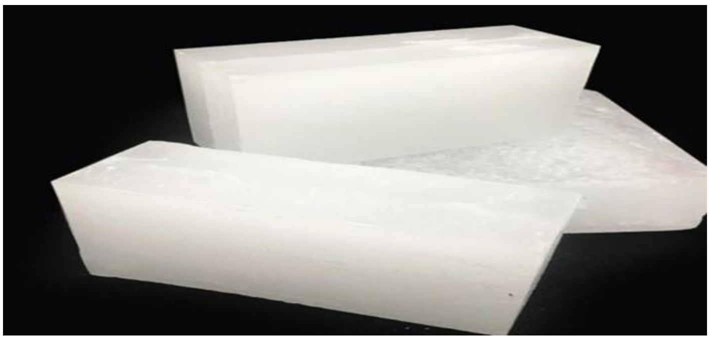


Temperature Indicator: An aquarium temperature meter, also known as an aquarium thermometer, is an essential tool for monitoring the temperature of an aquarium. Keeping the right temperature range is crucial for the health and well-being of aquatic life, as many fish and plants are sensitive to temperature fluctuations. The temperature indicator consists of 8 channels. Each channel receives input from different thermocouples which are incorporated in the energy storage unit.



Paraffin Wax: Paraffin wax is primarily composed of saturated hydrocarbons, typically ranging from C20 to C40 in chain length. It is a white or colorless solid at room temperature.



Coil Tube: Coils or copper pipes are other components of the coil tank whose job is to pass hot oil and steam through the boiler to eventually lead to the transfer of its temperature to the hot oil in the tank. The coils are installed in two types of U-shaped and Helically in the body and their number varies.

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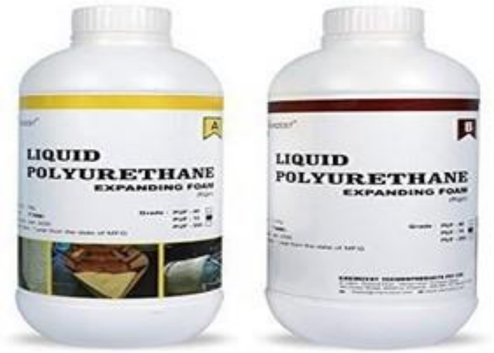
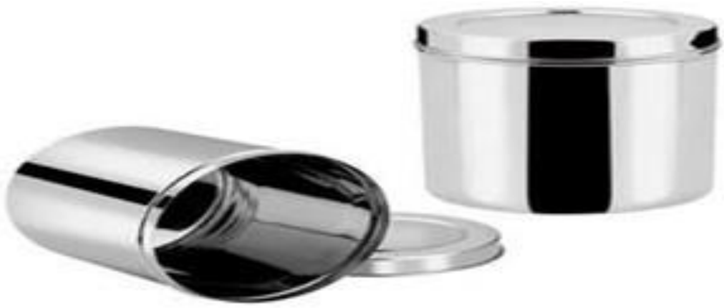
Liquid Polyurethane Foam (PUF): PUF is the two-part rigid foam system, When Part A on mixing with Part B at ambient temperature expands to form a light density, hard, rigid, closed cell foam. PUF is available in a wide range of Free Rise density (10- 400 Kg/m3) and pack core density (16-500 kg/m3). The foam prepared from PUF liquid not only have the best thermal properties but, it is the most versatile and fulfils the performance you need. It is highly effective in maintaining the thermal integrity of cold storage utility and maintains the temperature of the system.



Oil Storage Tank: Hot oil storage tanks are designed to store and manage high- temperature liquids, typically oils used in industrial processes, thermal energy storage, or heating systems. These tanks are engineered to withstand high temperatures and are constructed from durable materials to ensure safety and longevity.



Oil: Hytherm 600 is a reliable synthetic heat transfer oil designed for high-temperature applications. Its stability, low viscosity, and resistance to oxidation make it suitable for various industrial processes. Proper safety measures, maintenance, and monitoring are essential to ensure safe and efficient operation in systems using Hytherm 600.

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Testing procedure: The testing of the energy storage unit is done in two modes, charging and discharging. The temperature distribution of phase change material is studied in each mode to study melting and solidification pattern of the phase change material.

Charging: The procedure of testing in charging mode is as follows:

The water inside storage tank is heated to the range of 80-85 ºC using the heating arrangement. The flow control valve is adjusted to a suitable mass flow rate of heat transfer fluid. The initial readings of the temperature indicator are recorded. The pump is switched on to initiate the flow in the circuit. The readings of temperature indicator i.e. temperature at the predetermined points are then taken at an interval of 2 minutes, for around 40 to 60 minutes. The variation of temperature at each point in the wax is then plotted against time elapsed.

Discharging: The procedure for testing in discharging mode is as follows:
The heating arrangement of the storage tank is kept off. The initial readings of the temperature are recorded. The water in the storage tank at ambient temperature is circulated using the pump. The readings of temperature indicator i.e. temperature at predetermined points are taken at an interval of 2 minutes for around 40 to 60 minutes. The variation of temperature at each point in the wax is then plotted against the time elapse.

IV. WORKING

The main goal of the project is to use heat energy for cooking after daylight without the use of solar cell. The working of this unit is simple and procedure can be carried out easily. In the above diagram we can see that there are two major circuits to be run in this project. Circuit-1 consists of an oil tank, another tank having Phase change material stored in it, Oil pump, three phase motor, diaphragm control valve-1, diaphragm control valve-2 and the copper tube connecting the above equipment and heating coil acts acting as sun. Circuit-2 consist of PCM tank, Oil pump, three phase motor, two containers, diaphragm control valve-3, diaphragm control valve-4 and copper tubes connecting the second circuit.

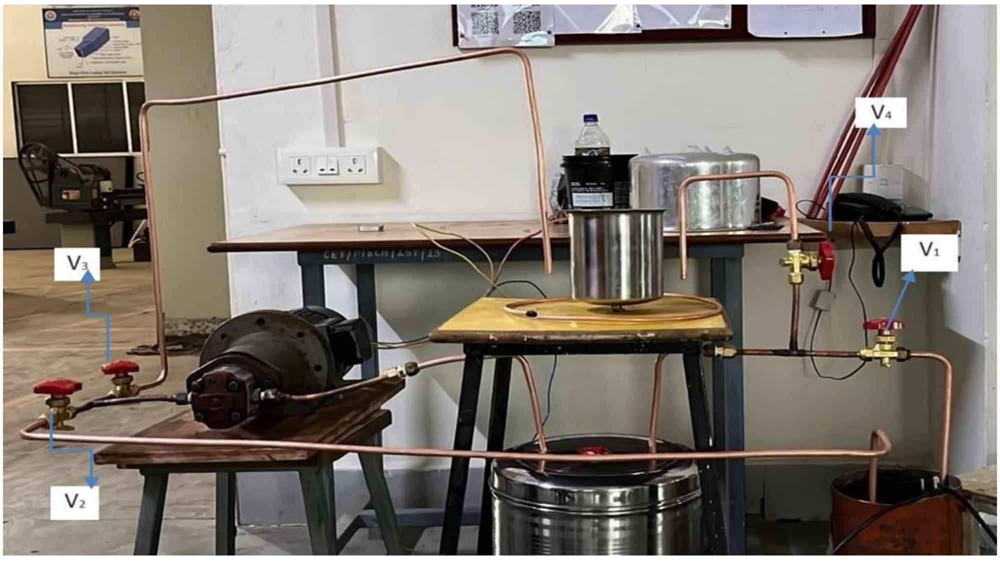

Image-1: Actual Experimental Setup

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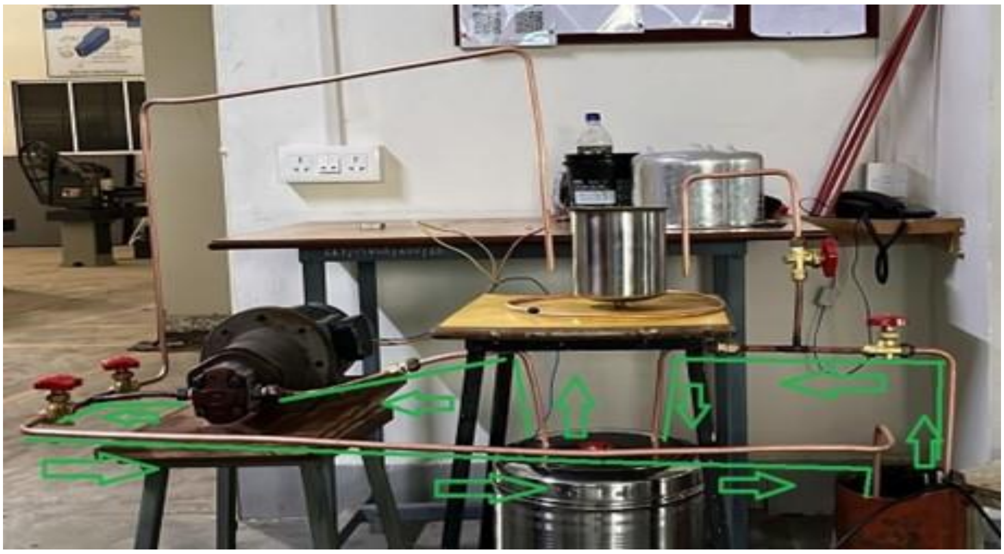

Image 2: Circuit - 1

The circuit 1 starts from the oil tank. The heating coil acts as sun for providing heat energy to the system. The heating coil is used to increase the temperature of the oil present in the oil tank. The oil present in the oil tank after reaching the required temperature, is further passed on in the circuit with the help of fuel pump. The copper tube from which oil is leaving the oil tank is kept at a certain height closer to the heater in such a manner that hot fluid can be carried out in the system. The copper tube entering the oil tank is kept deep in the oil tank so that the cold oil entering the tank can be collected at the bottom of the tank.

The fuel pump gets the required torque to pull the fuel from the oil tank with the help of three-phase motor. The oil pulled from the tank is further flown into the PCM storage tank with the help of copper tube. The PCM (In this project PCM used is paraffin wax having melting temperature of 37°C and melting temperature of 370°C) available in the storage tank is the most important component as it will absorb the heat present in the copper tube. The Phase Change Material (PCM) will convert from solid to liquid state with the help of copper tube carrying hot oil and store the heat for great amount of time. The PCM storage tank consists of copper tube in a spiral way so that the PCM available in the tank will absorb heat quickly. The spiral of copper tube can be increased and decrease according to required amount heat to be given. When PCM reaches the required temperature, both the diaphragm control valve, Valve1 and Valve2 in the circuit-1 is totally closed. The motto of circuit-1 is completed.

Image 3: Circuit - 2

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The circuit-2 should be started immediately after closing valve-1 and valve-2 and opening valve-3 and valve-4. When valve-1 and valve-2 are closed, valve-3 and valve-4 are opened so that the flow of oil is continue. Now, the oil running in circuit-2 has some amount of heat running in the circuit. When the oil is transferred in the container kept on the top of the apparatus, this running of oil in circuit-2 reduces the heating temperature present in the oil. To maintain this temperature, the oil is continuously flown through the Phase Change Material (PCM) with the help of copper tube. The PCM maintains the same or near to same amount of heating temperature for longer period of time. The container kept on the top of apparatus has another small container in which water is kept. Both the containers are attached with the help of nut and bolt. Both the containers have some space between them so that there should be continuous flow of oil in the circuit-2. This continuous flow of oil will increase the temperature of the water present in the small container. This continuous flow of oil in circuit-2 will increase the temperature of the small container having water in it Thereby, completing our goal to use heat energy for cooking after daylight without the use of solar cell.

The copper tube present in both the circuit should be insulated properly so that there should be very low loss of heat energy, when the oil is running in the circuit. The container having PCM should also be insulated so that there should be very low loss of heat when PCM is storing the heat energy. For insulation another container (bigger than one containing PCM) is kept outside the container having PCM. A liquified Polyurethane is used for insulation, this liquid is spread between both the containers which will help for insulation of PCM.

V. RESULT

Temperature of Oil:

	Time	Temperature (°C)
Heating Coil Start	11:15	0°C
	11:35	104°C

When system start:

	Time	Temperature of Oil (°C)
Working the system	11:40	85.8°C
	12:08	92°C
	12:18	94°C

Temperature of PCM:

	Time	Temperature of PCM (°C)
Paraffin Wax	11:40	36.3°C
	12:08	75.7°C
	12:18	84.5°C

Temperature of Boiling water:

	Time	Temperature of Boiling Water (°C)
Boiling Water	12:30	54.3°C
	12:45	60°C

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VI. CONCLUSION

The fabrication and testing of the Heat Energy Storage Unit (HESU) employing Phase Change Materials (PCMs) have demonstrated significant potential for enhancing energy efficiency and sustainability in various thermal energy storage applications. Through this project, we have successfully constructed a compact and reliable HESU capable of storing and releasing thermal energy efficiently. By harnessing the latent heat capacity of PCMs, our system effectively stores energy during the melting phase and releases it upon solidification, thereby enabling thermal energy management with minimal temperature fluctuations. Our experimental results have confirmed the viability and effectiveness of the HESU in providing stable and controlled thermal energy storage. The system exhibits rapid charging and discharging capabilities, allowing for quick response to varying energy demands and fluctuations in renewable energy sources.

Furthermore, the use of PCMs offers several advantages, including high energy storage density, thermal stability, and long-term durability, making it a promising solution for addressing energy storage challenges in diverse applications such as solar thermal systems, building HVAC systems, and industrial processes.

However, despite the promising results, some challenges and areas for further improvement have been identified. These include optimizing the selection and encapsulation of PCMs to enhance thermal conductivity and cycling stability, as well as scaling up the system for commercial applications while maintaining cost-effectiveness.

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