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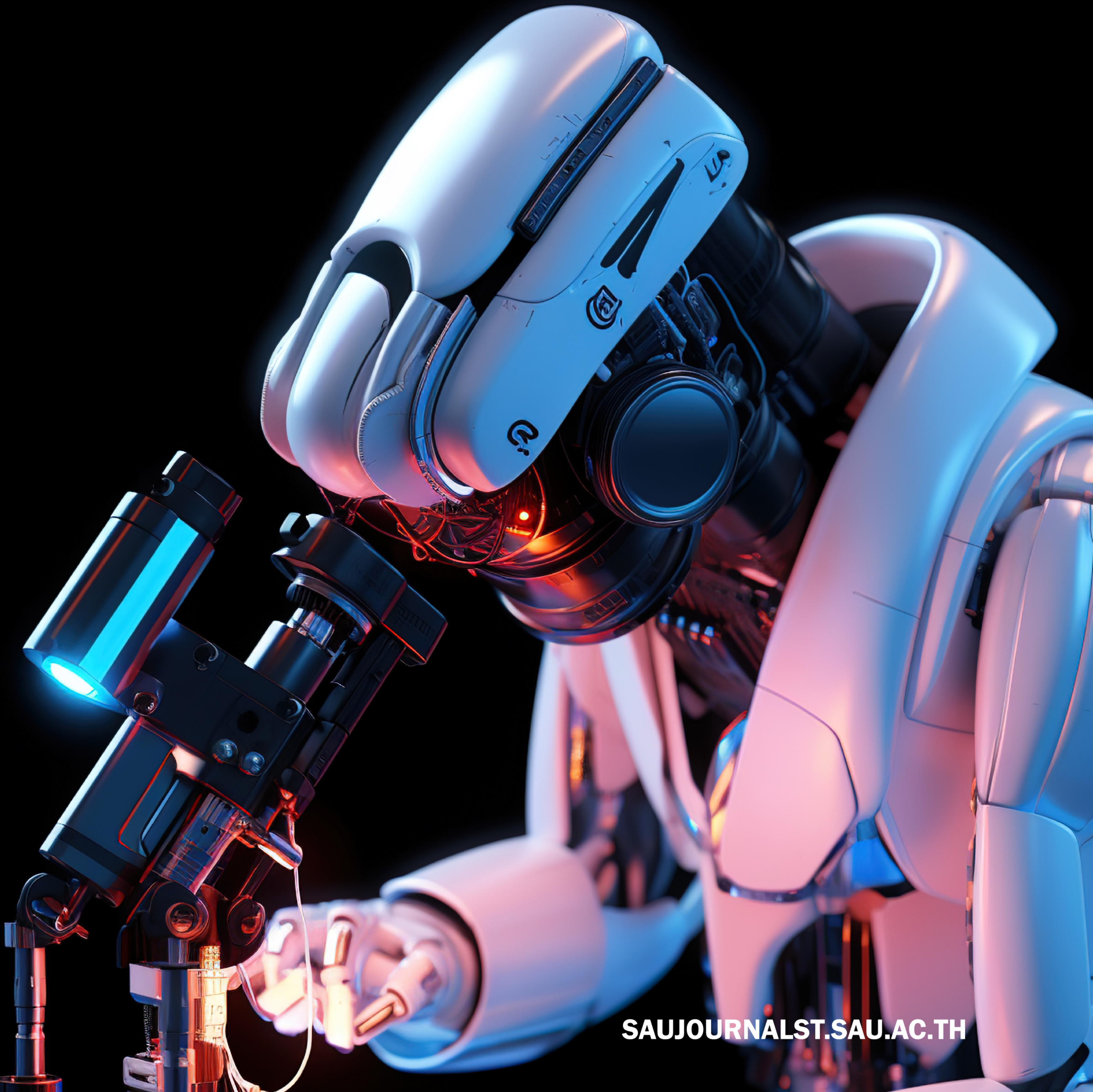

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จัดพิมพ์โดย มหาวิทยาลัยเอเชียอาคเนย์ ถนนเพชรเกษม เขตหนองแขม กรุงเทพฯ 10160

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วัตถุประสงค์

1. เพื่อเป็นเอกสารเผยแพร่ผลงานบทความวิจัยและบทความวิชาการ สาขา วิศวกรรมไฟฟ้า วิศวกรรมอิเล็กทรอนิกส์และโทรคมนาคม วิทยาการคอมพิวเตอร์ วิศวกรรมคอมพิวเตอร์ วิศวกรรมโยธา วิศวกรรมเครื่องกล วิศวกรรมอุตสาหการ อาชีวอนามัยและความปลอดภัย วิศวกรรมสิ่งแวดล้อม และวิศวกรรมเกษตร
2. เพื่อเป็นสื่อกลางในการแลกเปลี่ยนความรู้ใหม่ทางด้านวิทยาศาสตร์และเทคโนโลยี ระหว่างนักวิจัย นักศึกษาและผู้สนใจทั่วไป
3. เพื่อเป็นเอกสารรวบรวมรายงานและบทความวิจัยที่น่าสนใจ และมีคุณค่าทางวิชาการทางด้านวิทยาศาสตร์และเทคโนโลยี
4. เพื่อส่งเสริมและสนับสนุนให้เกิดองค์ความรู้ใหม่แก่นักวิจัยของมหาวิทยาลัยเอเชียอาคเนย์ นักศึกษาและผู้สนใจทั่วไป

ขอบเขต

เป็นเอกสารเผยแพร่บทความวิจัยและบทความวิชาการ (บทความวิชาการปริทรรศน์ บทความวิชาการเทคนิค บทความวิชาการพิเศษ) ทางด้านวิทยาศาสตร์และเทคโนโลยี

วาระการเผยแพร่

วารสาร SAU JOURNAL OF SCIENCE & TECHNOLOGY มีกำหนดออกปีละ 2 ฉบับ โดยฉบับที่ 1 จะจัดพิมพ์ระหว่างเดือนมกราคม-มิถุนายน ฉบับที่ 2 จะจัดพิมพ์ระหว่างเดือนกรกฎาคม-ธันวาคม ของทุกปี

ข้อคิดเห็นในบทความของวารสาร SAU JOURNAL OF SCIENCE & TECHNOLOGY เป็นทรรศนะส่วนตัวของผู้เขียน กองบรรณาธิการไม่จำเป็นต้องเห็นด้วย

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The main objectives of this journal are:

1. to publish research articles and academic articles in science and technology, Journal focus are Electrical Engineering, Electronics and communication Engineering, Computer Science, Computer Engineering, Civil Engineering, Mechanical Engineering, Industrial Engineering, Occupational Health and Safety, Environment Engineering and Agricultural Engineering;
2. to become a center for exchanging innovations in science and technology among researchers and interested persons;
3. to become a collection of interesting and valuable research papers and articles;
4. to promote and encourage Southeast Asia University researchers and interested persons to develop innovations.

Scope

To publish research articles and academic articles (Review articles, Technical article, Special Articles) in science and technology.

Schedule

SAU JOURNAL OF SCIENCE & TECHNOLOGY is published two issues annually. The first volume is published between January and June and the second is published July and December in each year.

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บทบรรณาธิการ

วารสาร SAU JOURNAL OF SCIENCE & TECHNOLOGY ปีที่ 10 ฉบับที่ 1 ประจำเดือน มกราคม – มิถุนายน พ.ศ. 2567 ปัจจุบันเป็นวารสารที่ได้รับรองให้อยู่ในฐานข้อมูลของ TCI 2

จากผลการดำเนินงานของวารสารฉบับนี้มีบทความที่น่าสนใจทั้งหมด 4 บทความ เป็นบทความวิจัย จำนวน 4 บทความ ซึ่งกองบรรณาธิการหวังเป็นอย่างยิ่งว่าผู้อ่านจะได้รับความรู้จากงานวิจัยต่าง ๆ ในวารสารเล่มนี้เป็นอย่างมาก

และในนามของ กองบรรณาธิการวารสาร ต้องขอขอบพระคุณ ผู้ประเมินบทความทุกท่าน ที่ยอมเสียสละเวลาอันมีค่าช่วยกลั่นกรองงานวิจัยให้มีคุณภาพยิ่งขึ้น รวมถึงคณาจารย์ นักศึกษา บุคคลทั่ว ๆ ไปทุกท่าน ที่ให้ความสนใจส่งบทความเพื่อเข้าสู่ขบวนการพิจารณาคุณภาพเพื่อตีพิมพ์เผยแพร่ ด้วยเหตุดังกล่าวนี้ทำให้กองบรรณาธิการทุกท่านมีกำลังใจเป็นอย่างมากในการพัฒนาวารสารฯ ให้มีคุณภาพยิ่งขึ้น

บรรณาธิการ

สารบัญ

Isolating hydrogen from water for diesel engine

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Abstract This paper focuses on designing a hydrogen separator for water and developing a hydrogen production and distribution system for a 4-stroke Compression Ignition Engine (CIE) with a displacement of 2,500 cc and a constant engine speed of 1,100, 1,300, 1,500, and 1,700 RPM. STL 316L stainless steel sheets are used for both the hydrogen water separator and control tools. Each of the 3 channels consists of 3 sets, totaling 42 sheets with 14 poles, including 7 negative and 7 positive poles. The efficiency of hydrogen gas separation from water is measured, revealing that 1,100 RPM results in the highest fuel consumption rate. The average consumption rate of mixed hydrogen gas is 226 CC/min, compared to 325 CC/min for diesel fuel, resulting in a fuel savings of 99 CC/min. In comparison to the electricity used, the highest electric current is 14 A, with an average power of 163 W for electricity at a DC voltage of 12 V. The tests demonstrate that the engine utilizes the least amount of power (146.41 W) and consumes the least amount of fuel (99 CC/min) at 1,100 RPM. Based on these findings, it is determined that utilizing a hydrogen gas separation system from water mixed with diesel fuel could result in a 40% fuel savings.

Keywords: diesel engine, isolating hydrogen, water for diesel engine

1. Introduction

In the current environment, the quantity of fossil fuels is dwindling, while their prices are rising [1]. Therefore, humans are seeking alternative energy sources to replace fossil fuels, particularly natural energy such as solar energy, wind energy, gravity energy, and water energy. Water, a vital resource for consumption, bathing, and various benefits, has a composition of (H_2O), consisting of 2 parts hydrogen (H) and 1part oxygen (O) [2-3].

When water is supplied to the hydrogen water separator in line with electrical and chemical principles, a gas separation reaction occurs, separating hydrogen gas as a combustible fuel from water. To achieve this separation for use as a co-fuel, scientists have developed and tested a hydrogen separator compatible with diesel, biodiesel, gasoline, LPG, and NGV for internal combustion engines.

Introducing hydrogen gas from the hydrogen separator into the intake manifold puts the engine in suction force mode, allowing air and hydrogen to be drawn into the combustion chamber. The combustion chamber of an internal combustion engine requires three components: fuel, air, and spark or compression [4]. H_2 gas becomes one of the fuels fired in the combustion chamber via the intake manifold, being a flammable gas.

Combining an electronic control unit (ECU) with a hydrogen water separator enables the engine to operate with reduced main fuel injection [5]. This aids in maintaining the primary fuel and, when mixed with it, completing combustion while simultaneously reducing emissions of pollutants and hazardous gases such as carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO), and particulate matter (PM2.5) [9].

Using the RPM signal, the ECU can control the production of hydrogen gas (H_2) to match the size and speed of the engine by adjusting the gas production as needed. The engine can transfer signals via the (H_2) ECU, reducing the system's electrical current needs (starting at only 1–10 Amp) [6].

Furthermore, to ensure safety, the system will automatically shut down if: the device exceeds specified electrical current consumption; the battery current falls below the specified level; the equipment's temperature surpasses the specified limit; or if the engine fails to start. Additionally, the system may feature a backfire prevention mechanism, advanced temperature control in the gas separator to avoid excessive heat, and the incorporation of a water tank as a secondary raw material for hydrogen gas separation.

The goal of this study is to separate hydrogen gas (H_2) from water and use the resulting hydrogen gas as a co-fuel in an internal combustion engine (ICE) alongside the engine's main fuel. The electronic control unit (ECU) and the power control system, which control all operations electronically, ensure the safety of the hydrogen separation system. After the engine starts moving, the electronic system will control devices that prevent backfires and regulate hydrogen production to meet the engine's needs. As soon as the engine is turned off, the system ceases gas production and continues to store it as water.

The objective of this research was to extract hydrogen gas (H_2) from water and utilize the resultant hydrogen gas as a co-fuel, combining it with the primary fuel of an internal combustion engine (ICE). In the process, a compression ignition engine (CIE) was employed to directly separate hydrogen gas from water using a distinct electrical process without the need for storage in a separate tank.

This approach differs from those presented in other articles or experiments, as it primarily focuses on the separation of hydrogen gas within industrial processes. The liquid is stored in a high-pressure tank while in a liquid hydrogen state, making the process significantly challenging and leading to prohibitively high production costs.

2. Technology of refuse-derive fuel

For the research and development of a system to separate hydrogen gas (H_2) from clean water and use it as fuel, mixed with the primary fuel of internal combustion engines, including both Compression Ignition Engine (CIE) and Spark Ignition Engine (SIE), the hydrogen separation system boasts a relatively high-security level. Every process is electronically controlled by a microcontroller or ECU. Hydrogen gas was blended with the primary fuel of internal combustion engines to serve as fuel. Subsequently, a power control system was equipped with a safety backfire mechanism and a method for regulating hydrogen production according to the engine's needs.

The acceleration of the engine is regulated by the electronic control unit (ECU). Once the engine stops, the gas separation system ceases gas generation and converts it to water. To reduce micro dust particles, the researcher investigated a water-to-hydrogen separator for mixing with diesel engine fuel (PM 2.5).

The control of hydrogen gas separation can be effectively adjusted based on the engine's size and the electronic control unit's speed for producing gas using the engine's speed (RPM) through the electronic control unit (ECU). This results in lower electrical power consumption for hydrogen gas separation (between 1 and 10 amps) [2]. To prevent accidents, the system will automatically cut-off if: the system consumes an excessive amount of electrical power; the battery's power level decreases; the system's temperature surpasses normal limits; or if the engine has not yet started. Additionally, there is a gas distribution control system that adjusts to accommodate the size of each engine, a backfire prevention system, innovations in gas temperature control, and a water tank designed to contain spare resources for separating hydrogen gas production.

Fig. 1 illustrates the design of a device for separating hydrogen gas from water, the development of a system for producing and distributing hydrogen gas for use in both compression ignition engines (CIE) and spark ignition engines (SIE) as internal combustion engines, and the effects of hydrogen gas consumption on internal combustion engines and security systems.

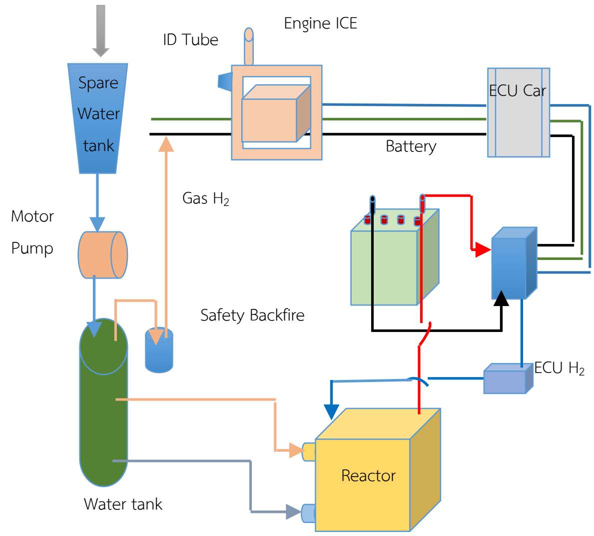


Fig.1 The design of the H_2 gas separation process and equipment.

The design of the hydrogen water separator included a device for separating hydrogen gas from water and a system for producing and distributing hydrogen gas for use in internal combustion engines, including both Compression Ignition Engines (CIE) and Spark Ignition Engines (SIE). The effects of hydrogen fuel gas on internal combustion engines and security systems were tested on vehicles with internal combustion engines, comprising both gasoline and diesel engines with a 4-stroke ignition type and a displacement ranging between 2,500 and 3,500 cc. An engine with displacement of 2,500 cc on a pick-up was equipped with a control system capable of adjusting the production of hydrogen gas based on the engine's rotational speed (RPM) or as required, to assist farmers in minimizing their production expenses; contribute to reducing air pollution small dust particles (PM 10 and PM 2.5), and toxic gases due to improper combustion of internal engines.

3. Data Analysis

The objective of this research was to extract hydrogen gas (H_2) from water and use the resulting hydrogen gas as a co-fuel combined with the primary fuel of an internal combustion engine (ICE). The hydrogen separation system was a relatively secure system since all operations were electronically controlled by the electronic control unit (ECU) and power control system. Following engine acceleration, the electronic system will control backfire prevention devices and other devices to regulate the generation of hydrogen to meet the engine's requirements. When the engine was shut off, the system stopped producing gas and continued to store it as water.

The decomposition of at least two precursors [2] via catalytic chemisorption allows for the dissociation temperature.

(Dissociation Temperature) is lower for the dissolution of water. With catalysts obtaining molecules of many substances through indirect chemical reactions occurring at temperatures below 1,00 K, thereby reducing the limitations of the thermal decomposition processes using catalysts. Most are compounds of halogen elements (halogen), such as ferrous chloride (ferrous chloride, $FeCl_2$), calcium bromide (calcium bromide, $CaBr_2$), and magnesium iodide (gI_2). The main limitations of catalytic decomposition reactions in industrial or commercial applications are high production costs and efficiency. of low process

$$2FeCl_2(s,l)+4H_2O(g) \longrightarrow Fe_3O_4(s)+6HCl(g)+H_2(g) \quad (1)$$

$$Fe_3O_4(s)+8HCl(g) \longrightarrow FeCl_2(s,l)+2FeCl_3(g)+4H_2O(g) \quad (2)$$

$$2FeCl_3(g) \longrightarrow FeCl_2(s,l)+Cl_2(g) \quad (3)$$

$$Cl_2(g)+H_2O(g) \longrightarrow 2HC(g)+1\text{-}2O_2(g) \quad (4)$$

$$2HCl(g) \longrightarrow H_2(g)+Cl_2(g) \quad (5)$$

Direct current is applied to the electrodes of an electrochemical cell to release the ions in the electrolyte solution. It moves to react at the electrode, as stated by [4]. Chemical reactions occur as either oxidation or reduction reactions in a direction that cannot occur spontaneously without an electric current. The electric current must be greater than the standard volt for the reaction to occur. For example, the electrolysis of water requires volts higher than 1.229 volts to produce hydrogen gas by hydrolysis. With electricity at the cathode, there is a reduction reaction of protons (hydrogen ions) in acidic conditions ($2H^+ + 2e^- \rightarrow H_2$), while in alkaline conditions, there is a reduction of water ($2H_2O + 2e\text{-}H_2 + 2OH^-$) at The anode can be oxidized to produce oxygen gas ($H_2O1/2O_2 + 2H^{+}+ 2e^-$), as shown in Fig. 4 The advantage of hydrogen gas production from this method is its high purity. The disadvantage is the high cost of electricity.

4. Methodology

4.1 Design and Result

The system design for a hydrogen separator from water, intended for blending with the fuel of an engine with a capacity of 2,500 cc (a small set designed for engines with capacities of no more than 3,500 cc), has been prepared, along with a corresponding set of control equipment. Additionally, STL 316L stainless steel sheets were employed in three sets and three channels, resulting in a total of 42 sheets with 14 poles— 7 negative poles and 7 positive poles (Fig.2).

Hydrogen gas (H_2) is a vehicle fuel alternative to LPG and NGV/CNG that can be produced by installing a system that separates hydrogen from water. It creates hydrogen gas in the form of ready-to-use gas, eliminating the need for a gas storage tank. The system is simple to install, takes up little space, functions semi-automatically using a microcontroller as its controller, and generates hydrogen gas (H_2) from water for use as a co-fuel with gasoline, diesel, LPG, and NGV. This study examined the fundamental ideas underlying the invention and development of hydrogen- powered automobiles, and therefore, a set of water-hydrogen separators was acquired. It was used in an electrolysis process to produce hydrogen, which was subsequently mixed with fuel in an internal combustion engine.

Fig.2 Small hydrogen gas separator from water complied with 2,500 cc engine.

Fig.3 Isolating hydrogen from water for use in a diesel engine of 2500 cc.

As can be seen in Fig.4, the separated hydrogen gas was introduced through the intake manifold and burned with the oil in the combustion chamber of the internal combustion engine.

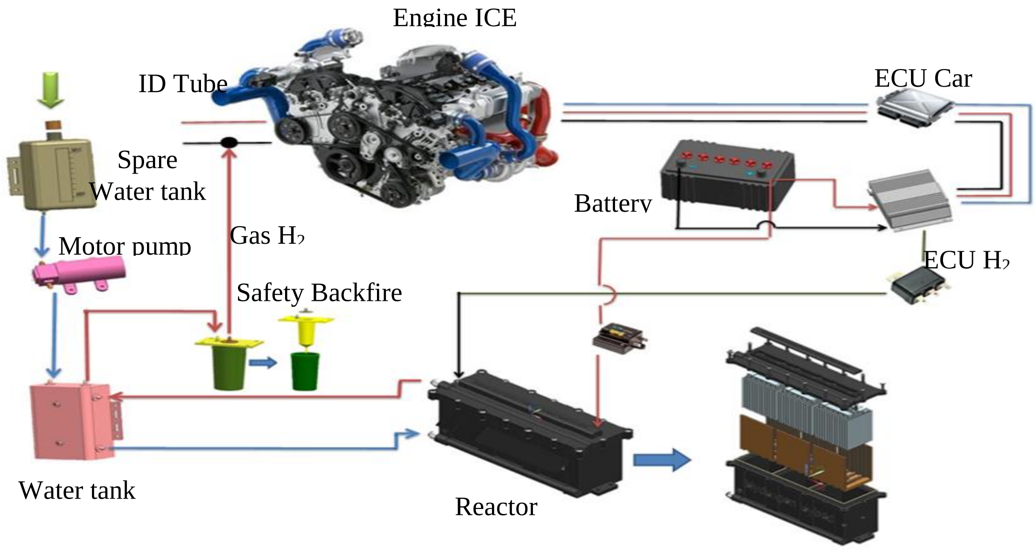


Fig.4 Hydrogen hybrid diagram.

The hydrogen separation system was a relatively secure system, as all operations were electronically controlled by the electronic control unit (ECU). The method employed involved adjusting the electrical contract to deliver less than the actual demand of the system and the power control system. After engine acceleration, the electronic system would control backfire prevention devices and devices regulating the generation of hydrogen to meet the engine's requirements. When the engine was shut off, the system ceased gas production and continued to store it as water.

This research incorporates a microcontroller system for separate process control tailored to the engine's requirements. The system efficiently regulates both electric current and maintains a consistent engine speed, resulting in reduced fuel injection in the vehicle.

Additionally, it can be automatically shut off in the event of separator overheating or when the car's battery reaches critically low levels. The microcontroller issues a command for the separation system to immediately cease operation until all conditions return to normal, resuming continuous operation there after. Notably, there is no other research where microcontroller controls are generated by directly utilizing both positive and negative electric currents, thus ensuring control over the aspects mentioned earlier.

Fig.5 illustrates the hydrogen control circuit, signal deception, or reduction in the equipment and sensors. This setup aims at diminishing the engine's oil consumption, with hydrogen subsequently added for compensation.

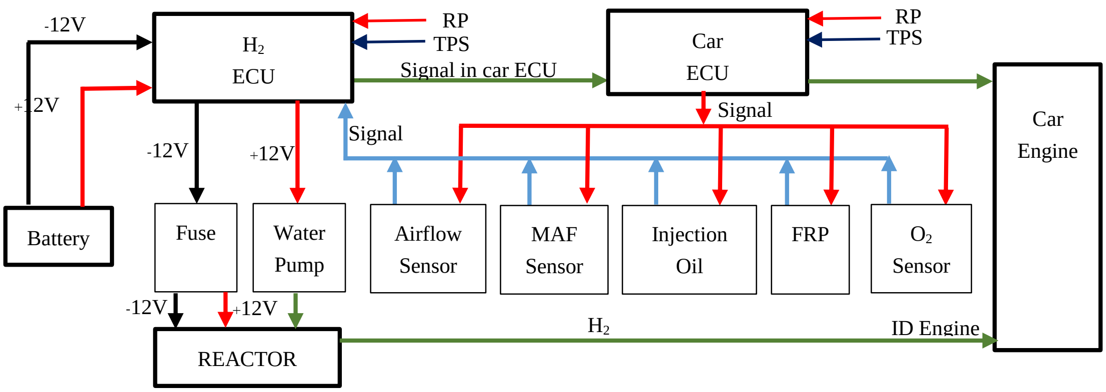


Fig. 5 Hydrogen control circuit diagram and signal deception or reduction of the signal for use in engines.

To reduce oil injection, the timing for lifting the fuel injector is adjusted for a shorter duration, with hydrogen gas injection as a replacement, as illustrated in Fig.6

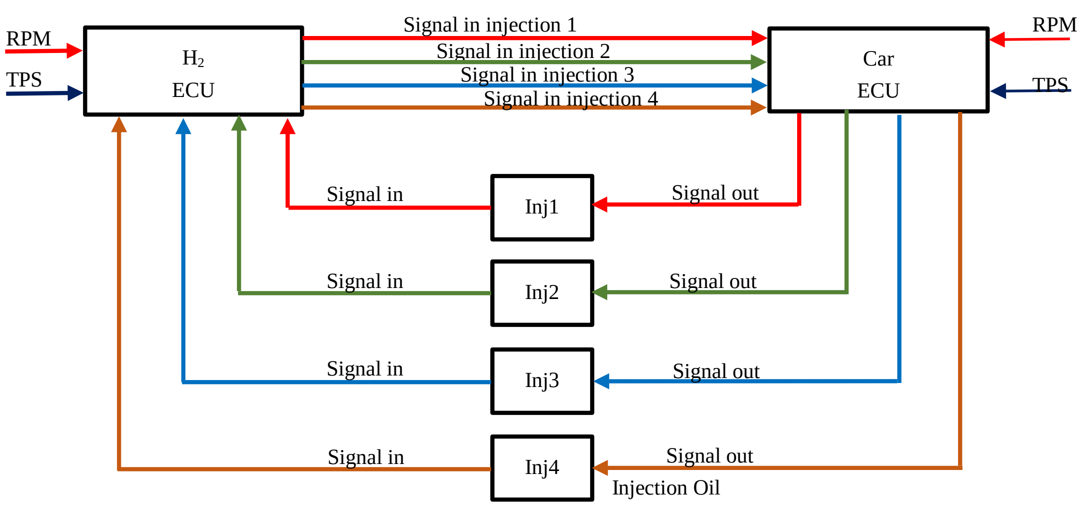
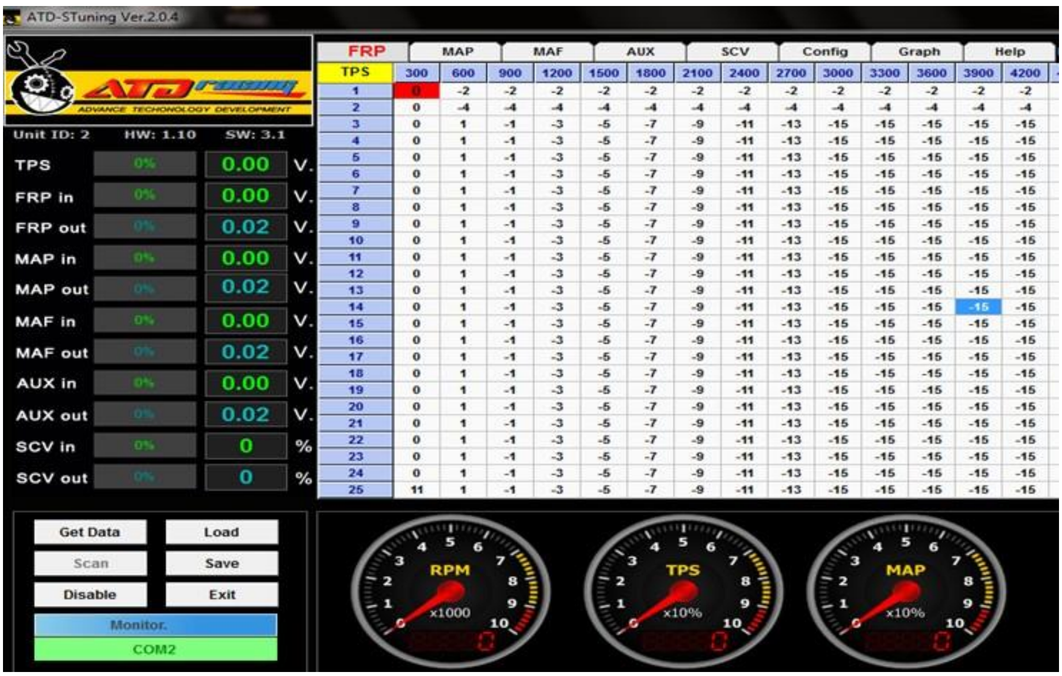


Fig. 6 Diagram of using the ECU to control hydrogen gas production and fuel injection.

By adjusting the fuel injector's pressure and resetting it to a negative value, the nozzle pressure will increase. This negative numerical division is determined by referencing the values in the table, where the FRP in value represents the actual value of the car, and the FRP out value is the value obtained from the adjustment. Through adjustment, by making the out value less than the in value by 10-20%, the pressure in the injector rail increases, resulting in a finer spray of fuel. This improved atomization enhances the mixing of fuel with hydrogen gas, as illustrated in Fig.7



TPS	300	600	900	1200	1500	1800	2100	2400	2700	3000	3300	3600	3900	4200
1	0	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2
2	0	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4
3	0	1	-1	-3	-5	-7	-9	-11	-13	-15	-15	-15	-15	-15
4	0	1	-1	-3	-5	-7	-9	-11	-13	-15	-15	-15	-15	-15
5	0	1	-1	-3	-5	-7	-9	-11	-13	-15	-15	-15	-15	-15
6	0	1	-1	-3	-5	-7	-9	-11	-13	-15	-15	-15	-15	-15
7	0	1	-1	-3	-5	-7	-9	-11	-13	-15	-15	-15	-15	-15
8	0	1	-1	-3	-5	-7	-9	-11	-13	-15	-15	-15	-15	-15
9	0	1	-1	-3	-5	-7	-9	-11	-13	-15	-15	-15	-15	-15
10	0	1	-1	-3	-5	-7	-9	-11	-13	-15	-15	-15	-15	-15
11	0	1	-1	-3	-5	-7	-9	-11	-13	-15	-15	-15	-15	-15
12	0	1	-1	-3	-5	-7	-9	-11	-13	-15	-15	-15	-15	-15
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16	0	1	-1	-3	-5	-7	-9	-11	-13	-15	-15	-15	-15	-15
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20	0	1	-1	-3	-5	-7	-9	-11	-13	-15	-15	-15	-15	-15
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23	0	1	-1	-3	-5	-7	-9	-11	-13	-15	-15	-15	-15	-15
24	0	1	-1	-3	-5	-7	-9	-11	-13	-15	-15	-15	-15	-15
25	11	1	-1	-3	-5	-7	-9	-11	-13	-15	-15	-15	-15	-15

Fig.7 Adjusting the pressure of the fuel injector

Hydrogen gas, obtained through water separation, is channeled into the water storage tank and then directed to the backfire prevention system. Fig.8 illustrates the engine's intake pipe for introducing hydrogen gas into the combustion chamber before suction. The water tank is stores water and replenishes the gas separator body with water to maintain system circulation.

The operational component of the gas separator collaborates with an electrical control unit (a microcontroller), which instructs the machine to either separate hydrogen gas from water or cease operations, while overseeing the system's functioning. Additionally, it regulates the separation of hydrogen gas from water to adapt to changes in engine speed.

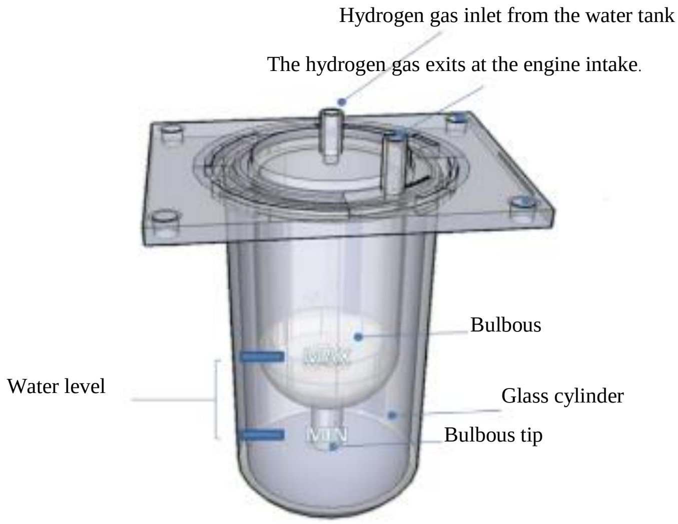

Fig. 8 Backfire arrester

5. Result and Discussion

The research was done by conducting initial tests on an unloaded 2,500 cc engine involved the design of a device for hydrogen gas separation from water, the development of a system for supplying hydrogen gas to the engine, and subsequent testing of the engine. Fig.4–7 display the results of experiments conducted at constant engine speeds of 1,100, 1,300, 1,500, and 1,700 revolutions per minute (RPM)

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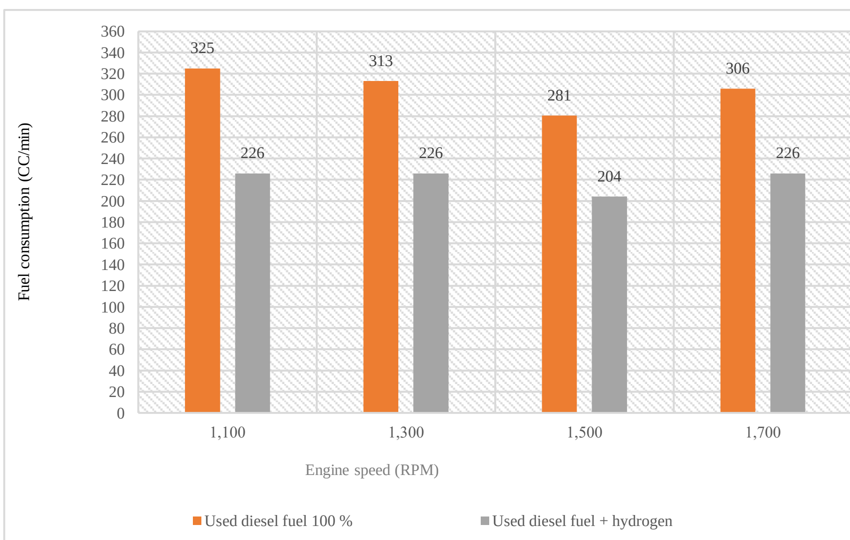

Fig. 9 Comparison of fuel consumption rates between using only diesel fuel and using diesel fuel combined with H_2.

Fig. 9 shows the comparison of fuel consumption rates between using only diesel fuel and using diesel fuel combined with H_2. The data was collected 5 times, for 15 minutes each time, at different speeds.

At constant engine speeds with varying RPMs of 1,100, 1,300, 1,500, and 1,700 revealed that, at 1,500 RPM, the fuel consumption rate was the lowest. When using only diesel fuel, the average consumption rate was 281 CC/min, and with the combination of diesel fuel and H_2, the average consumption rate decreased to 204 CC/min, resulting in a fuel savings of 77 CC/min. The highest fuel consumption rate occurred at 1,100 RPM. The average consumption rate using only diesel fuel was 325 CC/min, while combining diesel fuel with H2 resulted in an average consumption rate of 226 CC/min, leading to a fuel savings of 99 CC/min. At 1,300 RPM, there was a fuel savings of 87 CC/min, and at 1,700 RPM, the fuel savings amounted to 80 CC/min.

Electrolysis was employed to separate hydrogen gas from water for blending with engine fuel. This process utilized direct current electricity with a voltage ranging from 12 to 14.5 volts and an electric current between 10 and 13 amps to produce hydrogen gas, which was then mixed with the fuel. As illustrated in Fig. 10, tests were conducted at constant engine speeds of 1,100, 1,300, 1,500, and 1,700 RPM.

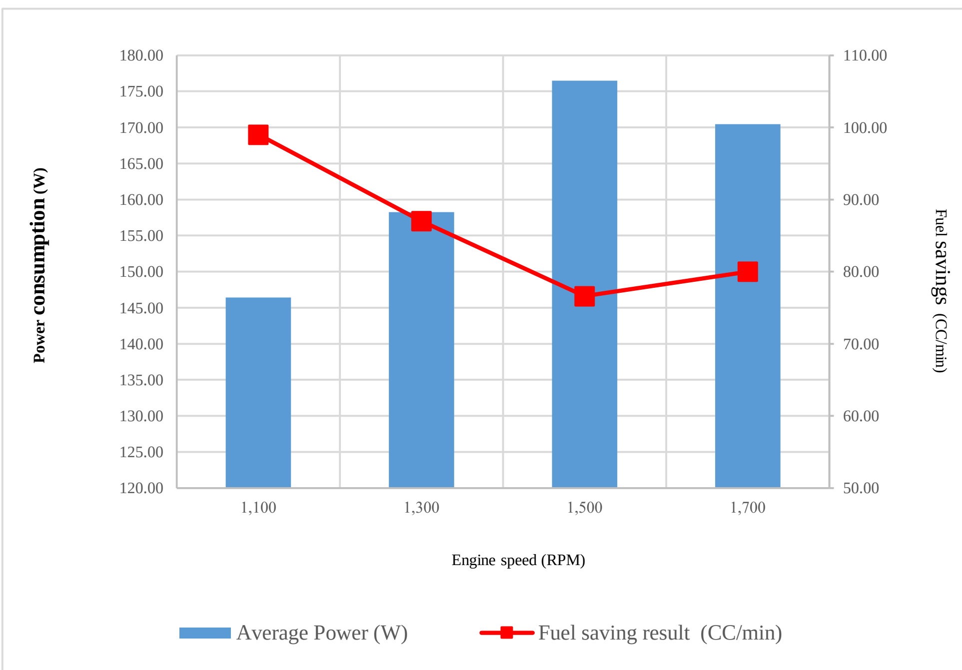

Fig. 10 Means of power consumption compared to fuel savings

As shown in Fig.10, the electricity used to separate hydrogen gas from the water was derived from car batteries that had been charged by the engine's alternator. In this test, a DC voltage of 12 volts, a maximum current of 14 A, and an average power of 163 W were utilized. At 1,100 RPM, the engine consumed the least amount of power, 146.41 W, according to this test, resulting in a 99.00 CC/min fuel savings, or 68 CC/ min/ W when demonstrated as a ratio of fuel savings to power consumption. As for the engine speed at 1,500 RPM, it consumed the most power, 176.46 W, resulting in fuel savings of 76.60 CC/min or accounting for a ratio of fuel savings to the power consumption of 43 CC/min/W, whereas the engine speeds at 1,300 and 1,700 RPM accounted for ratios of fuel savings to the power consumption of 55 and 47 CC/min/W, respectively.

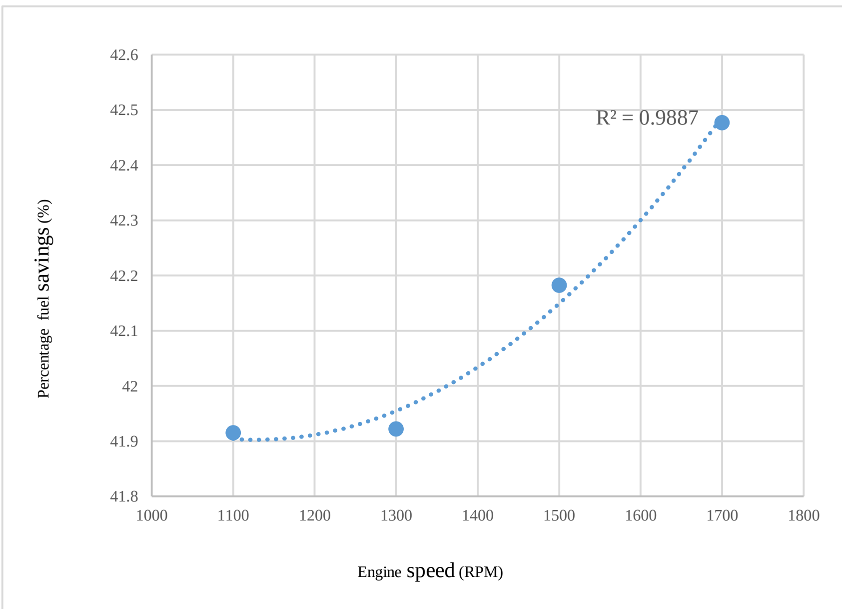

Fig. 11 Percentage of fuel savings from consumption of H_2 fuel obtained from water separation (%)

Fig. 11 shows the results of tests conducted at various engine speeds, based on the percentage of fuel savings achieved by using H_2 fuel separated from water and mixed with diesel fuel. It can be seen that the percentage of fuel savings tends to increase at higher engine speeds, with a trend line modeled as a polynomial with an R^2 value of 0.9887.

Engines that use fuel mixed with hydrogen gas produce a certain amount of pollution. This pollution is measured by assessing the levels of black smoke, PM10, and PM2.5 from combustion. A comparison is then made between the emissions using 100% fuel and those with hydrogen is mixed with the fuel according to various engine speeds, as shown in Fig.7.

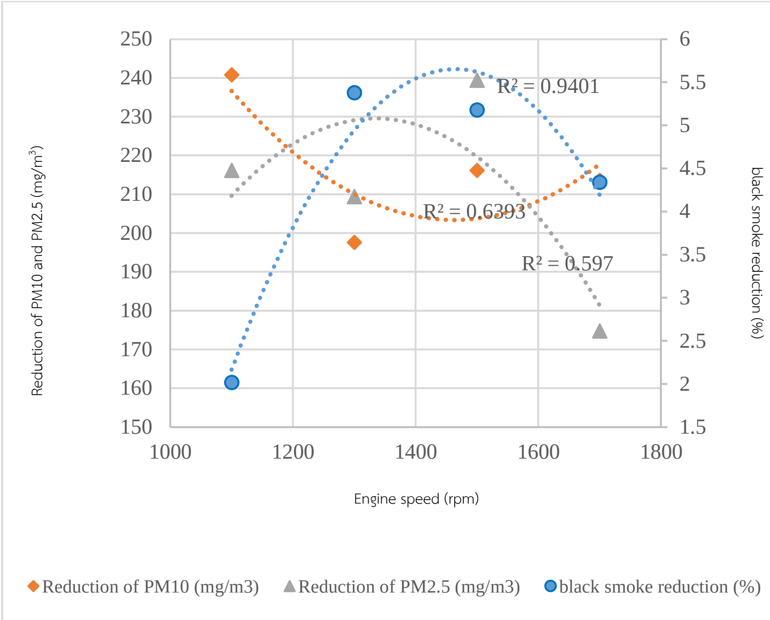

Fig. 12 Comparison of reduction of black smoke (%) with PM 10 and PM 2.5 at different engine speeds

Fig. 12 is a comparison of the reduction of black smoke (%) with PM 10 and PM 2.5 at different engine speeds. found that the trend toward reducing the amount of black smoke At 1,400–1,500 rpm, black smoke is released more than at other rpms. The amount of fuel must be tested again. PM 10 emissions will be less at 1,400–1,500 rpm and PM. 2. 5 when the engine speed increases. comes in smaller quantities.

5. Conclusions

In conclusion, the primary goal of this research was to extract hydrogen gas from water, aiming to utilize it as fuel for internal combustion engines as a cleaner alternative to conventional fossil fuels. An additional objective was to address prevalent air pollution resulting from incomplete combustion in existing diesel engines. Experimental tests were conducted on both a 2,500-cc engine and an unloaded engine, spanning constant speeds of 1,100, 1,300, 1,500, and 1,700 RPM.

Analyzing the test results revealed that the highest fuel consumption occurred at 1,100 RPM. Specifically, while the average consumption rate for diesel fuel alone was 325 CC/min, the introduction of hydrogen gas reduced it to 226 CC/min, resulting in substantial fuel savings of 99 CC/min. In terms of electrical usage, the highest recorded electric current at 14 A, corresponding to an average power of 163 W, was observed at 1,100 RPM. Notably, this speed also demonstrated the engine's optimal energy efficiency, consuming a minimal amount of energy at 146.41 watts and preserving the most gasoline at 99 cc/min.

As of September 30, 2022, Thailand had 1,041,920 diesel-powered vehicles, mandated by legislation requiring diesel propulsion [10]. With an average daily consumption of 60 liters per vehicle [3], the nation collectively consumed approximately 62.52 million liters of diesel daily. If the clean energy generated from the hydrogen-water separation process were harnessed as fuel for diesel engines, the potential reduction in daily diesel consumption could reach 26.25 million liters, presenting a significant environmental benefit. Previous studies have suggested that integrating a hydrogen gas separation device with diesel fuel may result in a substantial 40% reduction in gasoline usage.

Abbreviations

°C	*Degree Celsius*
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
H_2	Hydrogen
H_2S	Hydrogen Sulfide
N_2	Nitrogen
η_g	Synthetic Gas
O_2	Oxygen
RPM	Revolutions per minute
cc	Cubic Centimeters
CC/min	Cubic Centimeters Per minim
W	Watt
LPG	Liquefied Petroleum Gas
NGV	Natural Gas for Vehicles
CNG	Compressed Natural Gas
PM10	Dust particles in the air have a diameter of 10 microns.
PM2.5	Dust particles in the air have a diameter of 2.5 microns.

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Energy Efficiency Analysis of Permanent Magnet Synchronous Motors in the Whole Life Cycle of Urban Rail Vehicles

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บทคัดย่อ บทความนี้วิเคราะห์ประสิทธิภาพการใช้พลังงานของมอเตอร์ซิงโครนัสที่ใช้แม่เหล็กถาวร (PMSM) ตลอดวงจรชีวิตของยานพาหนะที่ใช้รางในเมือง โดยใช้ยานพาหนะ PMSM จากเส้นทางรถไฟเป็นตัวอย่าง โดยใช้ข้อมูลการทำงานของยานพาหนะจริงเพื่อสร้างแบบจำลองการใช้พลังงานของยานพาหนะ จากนั้นจะประเมินวงจรชีวิตเต็มของค่าการใช้พลังงานของยานพาหนะ PMSM ในทางสถิติ รวมถึงการใช้พลังงานระหว่างสี่ช่วงของการเร่งความเร็ว ความเร็วสม่ำเสมอ การเบรก และการหยุดรถ รวมถึงพิจารณาการใช้พลังงานและต้นทุนของยานพาหนะอย่างครอบคลุมและดำเนินการวิเคราะห์เปรียบเทียบระหว่างยานพาหนะที่ใช้มอเตอร์ซิงโครนัสแบบแม่เหล็กถาวร (PMSM) และมอเตอร์แบบอะซิงโครนัส (AM) ผลลัพธ์แสดงให้เห็นว่ายานพาหนะที่ใช้มอเตอร์ซิงโครนัสแบบแม่เหล็กถาวรสามารถประหยัดพลังงานและต้นทุนได้ 40% และ 36% ตลอดวงจรชีวิต ตามลำดับ ข้อมูลนี้แสดงให้เห็นว่ายานพาหนะที่ใช้มอเตอร์ซิงโครนัสแบบแม่เหล็กถาวรมีข้อได้เปรียบในการประหยัดพลังงานตลอดวงจรชีวิตเป็นอย่างมาก ดังนั้นยานพาหนะที่ใช้มอเตอร์ซิงโครนัสแบบแม่เหล็กถาวรจึงช่วยลดการใช้พลังงานในการใช้งาน ทำให้ประหยัดและเพิ่มความเป็นมิตรต่อสิ่งแวดล้อมของยานพาหนะ บทความนี้ให้ข้อมูลเพื่อสนับสนุนการเพิ่มประสิทธิภาพและการควบคุมการใช้พลังงานในยานพาหนะที่ใช้รางในเมือง

คำสำคัญ: PMSM, ยานพาหนะรางในเมือง, วงจรชีวิตทั้งหมด, ประสิทธิภาพการใช้พลังงาน, การขนส่งสาธารณะ, ความคล่องตัวในเมือง

Abstract This paper analyses the energy efficiency of Permanent Magnet Synchronous Motors (PMSM) throughout the entire life cycle of urban rail vehicles, using a vehicle with PMSM from a metro line as an example. The paper utilizes actual vehicle operation data to establish a model for vehicle energy consumption. It then statistically estimates the full life cycle of the energy consumption value of the vehicle with PMSM , as well as the energy consumption during the four phases of individual acceleration, uniform speed, braking, and stopping. This paper comprehensively considers vehicles' energy consumption and cost and conducts a comparative analysis of the PMSM and asynchronous motors (AM) vehicles. The results show that the vehicle with PMSM saves 40% and 36% of energy consumption and cost throughout the life cycle. The data presented in this paper demonstrates that vehicle with PMSM offer significant energy-saving advantages throughout their life cycle. Therefore, the PMSM reduces operational energy consumption and improves the economy and environmental friendliness of the vehicles. The paper provides data to support the optimization and control of energy consumption in urban rail vehicles.

Keywords: PMSM, Urban rail vehicles, Whole life cycle, Energy efficiency, Mass public transport, Urban mobility

1. Introduction

Urban rail transport is becoming increasingly concerned with energy efficiency and operating costs. The majority of drive chain losses in urban rail vehicles are attributable to motor inefficiency. An attractive solution to reduce these losses and the associated energy consumption is the implementation of PMSM technology [1]. PMSMs are preferred due to their high efficiency, high power factor, high power density, direct drive, fully enclosed structure, lighter weight, and excellent dynamic performance compared to AM [2-6]. PMSMs are suitable for high-speed trains, urban rail vehicles, and other similar applications. The structure of the PMSM is illustrated in Figure 1.

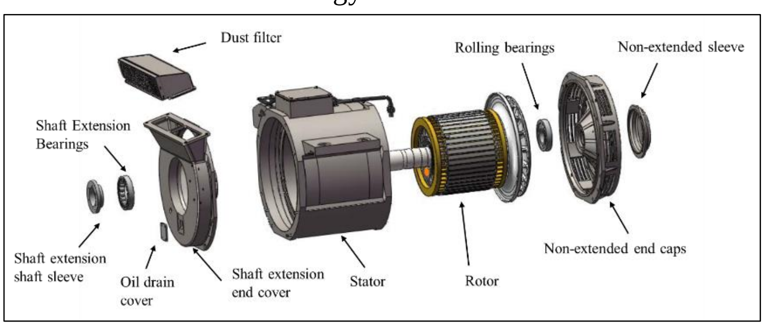


Fig. 1 Structure of the PMSM.

There is a growing trend among domestic and foreign scholars to research the application of PMSM in urban rail vehicles. Khare and Shriwastava [7] investigated the weak magnetic control algorithm of the PMSM drive for light vehicles. The importance of PMSM flux weakening for traction drives was discussed, along with the advantages and requirements of PMSMs in traction applications. They also analyzed the effects of different low/high speed modes on the network from an EMC point of view through simulation experiments. The research showed that PMSM have advantages in terms of low volume and direct drive of wheels. Liu et al. [8] conducted a line simulation to compare the energy consumption of the permanent magnet synchronous traction system with the asynchronous traction system. The comprehensive energy-saving rate of the permanent magnet traction system was found to be between 6.6% and 36.9%. Zhang et al. [9] analyzed the advantages and disadvantages of PMSM in the field of rail transportation. The study also covered the control strategy of high-power traction inverters and the weak magnetism control technology of traction motors. The basic theory, structure design, and control method of the permanent magnet traction system had been initially established. Kondo et al. [10] conducted a study on the energy consumption of PMSM for railway vehicle traction and showed that the total loss of PMSM is approximately 60% less than that of AM. This was achieved by establishing equivalent circuit and loss models. A comparative study on the efficiency of permanent magnet traction motors and AM was conducted by Qi et al. [11]. The results showed that the rated operating point efficiency of PMSM is approximately 5% higher than that of AM. The advantage of the efficiency in the low-speed zone was even more pronounced, with an improvement of over 10% in the operating point efficiency. Franko et al. [12] conducted a study on the design and performance of AM and PMSM. They experimentally confirmed that improving the rotor of the PMSM could reduce loss, improve efficiency, and increase it by 2% compared to the AM. Recently, Yan and Wirogana [13] analyzed the energy transfer and dissipation in urban rail vehicles. Traction power consumption was found to account for approximately 50% of the system power consumption.

Table. 1 Line parameters.

Parameter	Value
Line length	22,700 m
Number of stations	18 seats
Average gradient	0.015
Average curvature	0.0025 m^{-1}
Average traveling speed	32.2k m/h
Average stopping time	43.3 s
Average running time per day	0.78 h

Further exploring the potential energy-saving impact of PMSM is interesting. Since PMSM technology offers significant efficiency advantages, it is essential to consider its long-term benefits. This study presented a comprehensive analysis of the energy efficiency of PMSM throughout the entire life cycle of urban rail vehicles. The aim was to evaluate the energy savings, and operation and maintenance costs associated with the use of these motors, providing a reference for the selection of energy-saving technologies for urban rail vehicles.

2. Research Methods

This study employed the Metro Line 5 in a city in central China as an example, providing information on its line conditions and vehicle parameters in Table 1 and Table 2.

The vehicle control unit integrates fault recorder and data logging functions to record status information on key control units and components of the vehicle. The Train Control and Management System (TCMS) then parses the required operational data. Figure 2 displays the TCMS data parsing interface.

Table. 2 Parameters of the study vehicles.

parametric	Vehicles with PMSM
Vehicle mass	189,000 kg
Average passenger capacity	63,000 kg
Maximum running speed	80 km/h
Acceleration (0-80km/h)	$\geq$0.6 m/s^2
Coefficient of adhesion	0.158
Traction efficiency	0.98
Braking efficiency	0.98
Maximum Traction Force	360 kN
Maximum braking force	340 kN
Maximum power	3,040 kW
Maximum energy recovery	0.35
Battery capacity	437 Ah
Battery efficiency	0.9
Battery temperature (20°C) coefficient	0.86
Air Conditioning Power	22.8 kW
Lighting power	2.6k W
Design Life	30 years

MATLAB is then used to extract and analyze this data, calculating various parameters such as time, state, energy consumption, mileage, and other relevant factors for each stage of the vehicle's operation. Figure 3 shows the script editing interface for visual analysis of data in MATLAB. Such parameters were then used to construct a model of the vehicle's energy consumption, allowing for an estimation of the total energy consumption over the vehicle's entire life cycle.

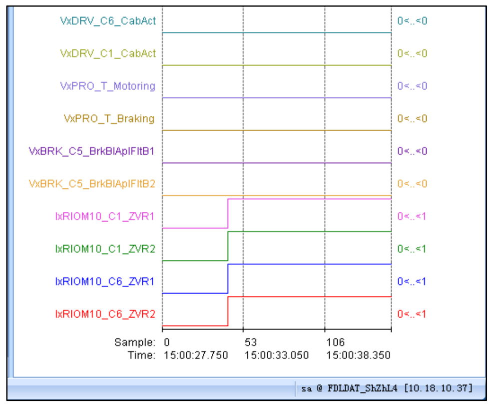


Fig. 2 Data parsing interface.

Fig. 3 MATLAB script editing interface.

Simultaneously, the economic perspective would consider the procurement, maintenance, and energy costs of both motor types, as well as calculate the total cost in the whole life cycle of the vehicle with PMSM. The comparison of vehicle energy consumption and cost between the two motors would, then, reveal the energy-saving benefits of PMSM in the life cycle of urban rail vehicles, along with their advantages and limitations.

2.1 Calculation of vehicle energy consumption

Energy generation for vehicle operation was calculated in seconds. During traction mode, energy flows from the catenary to the wheels, resulting in positive power on the wheels. During regenerative braking mode, energy flows from the wheels back to the power system, resulting in negative power on the wheels. The vehicle's auxiliary energy consumption mainly included battery chargers, passenger room air conditioning, and lighting. Following the vehicle energy consumption model proposed by Wang et al. and Jenks et al. [14, 15], this study first collected the real-time time, speed, mileage, and other data of a vehicle traveling through a large intersection (including both ends of the turnback) through the TCMS system. The vehicle operation curve is shown in Figure 4.

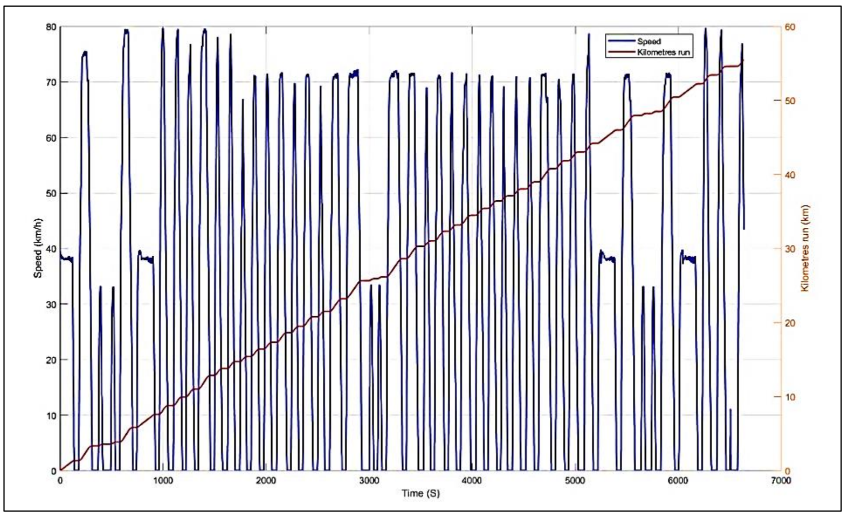


Fig. 4 The typical vehicle running curve.

The vehicle operation process, due to its cyclical characteristics, included four phases: acceleration, uniform speed, braking, and stopping. To facilitate calculation, this study counted the time, energy consumption, and mileage data corresponding to acceleration, uniform speed, braking, and stopping in 20 cycles (i.e., one major intersection). As a result, based on the traction energy consumption during acceleration and uniform speed, the regeneration energy consumption during braking, and the auxiliary energy consumption for the whole operation in the grand interchange, the unit traction energy consumption of 285 kWh, the unit auxiliary energy consumption of 39kWh, the unit regeneration energy consumption of 162kWh, and the unit total energy consumption of 162kWh were calculated.

Based on a large intersection, the energy consumption of vehicles throughout their entire life cycle was calculated. With an average daily operating time of 15-18 hours, the crossing calculation took approximately 0.78 hours. The vehicle maintenance stops, and the operation of the crossroads were taken into consideration. Therefore, the energy model for the PMSM in urban rail vehicles throughout their life cycle would be defined in Equations (1) and (2).

$$N_C = \frac{T \times D}{0.78} \quad (1)$$

Where N_c is the number of operational intersections, T is the average daily operating time, and D is the number of operating days per month.

$$\begin{cases} E_y = E_u \times N_C \\ E_t = \sum_{n=1}^{30} E_y \end{cases} \quad (2)$$

Where E_y type annual energy consumption, E_u is unit energy consumption, E_t is total energy consumption.

2.2 Calculation of traction motor cost

To enhance the economic performance of PMSM, AM was employed as a benchmark for analyzing the costs associated with the entire life cycle of urban rail vehicles. This comprehensive analysis encompassed procurement costs, as well as operation and maintenance costs.

The unit prices for procuring the two types of traction motors were derived from their respective procurement contracts. These prices were then utilized in the computation of the overall procurement costs. Additionally, drawing upon the actual outsourcing cost data from metro lines in select Chinese cities [16], the unit prices for vehicle frame repair and overhaul served as the primary input for the calculation of operation and maintenance costs associated with traction motors, as detailed in Table 3.

Table. 3 Motors Cost Comparison.

Project	**AM (RMB 10,000/unit)**	**PMSM (RMB 10,000/unit)**
Procurement	9	10.1
Frame repair	0.9185	1.27
Overhaul	1.8	2.1

According to the "Management Measures for Operation and Maintenance of Urban Railway Transport Facilities and Equipment" [17], the frame repair interval should not exceed 5 years or 800,000 vehicle kilometers, while the overhaul interval should not exceed 10 years or 1.6 million vehicle kilometers. Additionally, the traction motor user manual should be consulted. The plan for estimating the vehicle design life cycle of traction motor procurement and maintenance costs based on a frame repair interval of 5 years and an overhaul interval of 10 years was outlined.

It was recommended that each train undergo 3 frame repairs and 3 overhauls.

3. Results and Discussion

3.1 Energy consumption

According to Section 2.1, the unit energy consumption value was brought into equation (1) to obtain the total energy consumption of the vehicle over its entire life cycle (as shown in Figure 4).

Figure 5 illustrates the energy consumption and train operation routes of the vehicle with PMSM throughout its entire life cycle. On the left side of the axis, the bar represents the total annual energy consumption, while the right side displays the number of train operation routes with the broken line indicating the annual train operation routes. The vehicle completes 179,397 train operation routes over its entire life cycle, operating approximately 4,484,913 km, with a total energy consumption of 29,062.24 MWh.

Based on the research data from Deng and Zhong [18], the unit energy consumption of the asynchronous traction motor vehicle was 10.99 kWh/km. Assuming that it covered the same mileage as the vehicle with PMSM throughout its life cycle, its total energy consumption would be approximately 49,289.20 MWh, as presented in Table 4. The data showed that the vehicle with PMSM has a lower whole life cycle energy consumption compared to the asynchronous traction motor vehicle with 41% energy consumption saving (20,226.96 MWh).

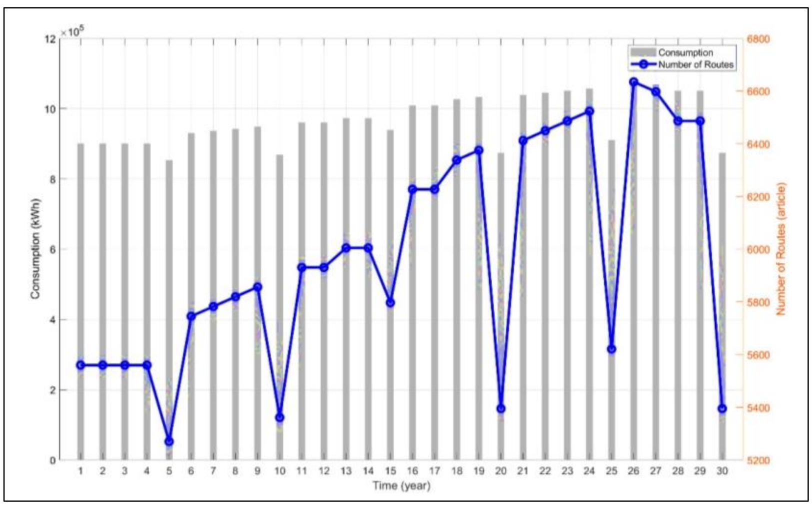


Fig. 5 Energy consumption and Train operation route.

Table. 4 Life cycle energy and electricity consumption values.

Vehicle type	**Total energy consumption (MWh)**	**Total Electricity Consumption (10,000 RMB)**
Vehicle with AM	49,289.20	2978.05
Vehicle with PMSM	29,062.24	1755.94

Figure 6 displayed the four stages of operation and energy consumption of a vehicle with PMSM at a large intersection; they were acceleration, uniform speed, braking, and stopping stages. The data indicated that the entire process had a total cumulative acceleration of 620 s, covering a distance of 8.35 km and consuming 224 kWh of traction energy. During the uniform speed operation, it took 557 s to cover 10.05 km, consuming 61 kWh of traction energy and 9 kWh of regeneration energy. Additionally, it took 755 s to operate 8 km during the braking, generating 153 kWh of regeneration energy. The average traction energy consumption per kilometer and the total energy consumption are 15.49 kWh and 6.48 kWh. Compared to the asynchronous traction motor vehicle's energy consumption of 16.39 kWh and 10.99 kWh/km [18], the PMSM vehicle's energy consumption of 49 kWh and 6.48 kWh/km demonstrated a significant improvement in energy efficiency and regeneration rate. The less energy consumption revealed the advantages of using a PMSM.

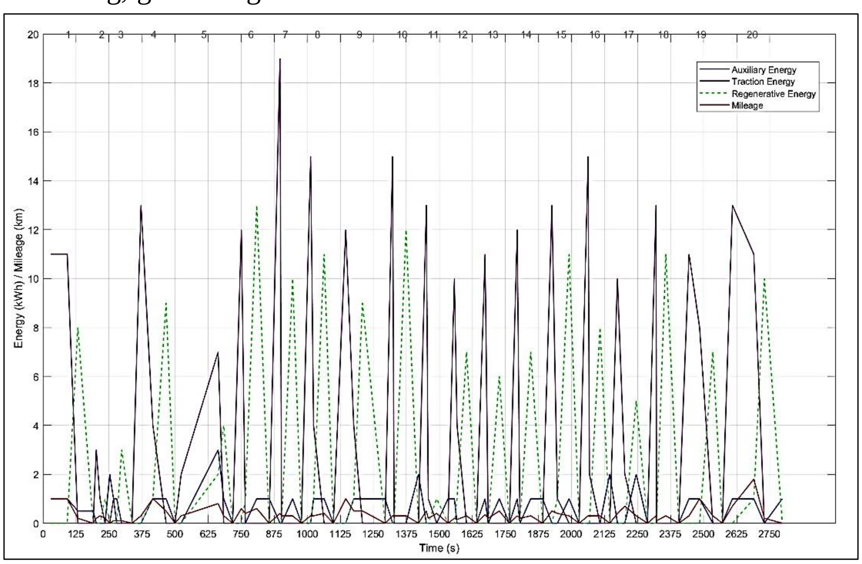
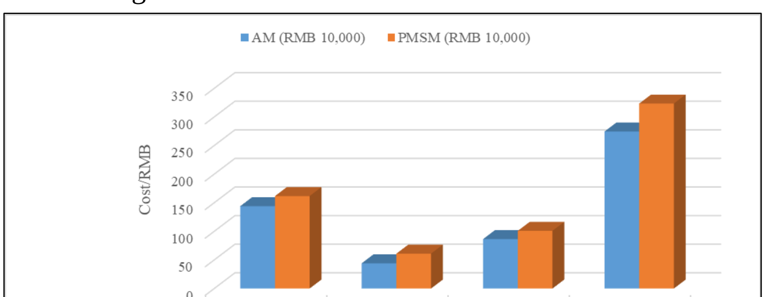


Fig. 6 Vehicle operating energy consumption/mileage.

3.2 Economic aspects

For the economic performance of the AM and PMSM, the electricity cost of the two different motors during the whole life cycle of the vehicle, as referred to China's urban railway electricity cost (with 0.6042 RMB/kWh), was shown in Table 4. The total cost of electricity in the entire life cycle of vehicle with PMSM is approximately 17,559,400 RMB, which is a saving of about 12,221,100 RMB compared to asynchronous traction motors. From section 2.2, the expenses for procurement and maintenance throughout the entire lifespan of vehicles with two different types of motors are presented in Figure 7. The cost analysis showed that the PMSM had a procurement cost of 1,616,000 RMB (which was 176,000 RMB higher than that of the asynchronous traction motor). Likewise, the maintenance cost of PMSM was 1,617,600 RMB, which was 312,700 RMB higher than the asynchronous traction motor. As a result, the total cost of the PMSM was also 488,700 RMB higher than the asynchronous traction motor, representing an increase in cost of approximately 17.8%. Such total cost was attributed to the current scarcity of permanent magnet materials for PMSM, making the production and manufacturing costs more expensive compared to AM [19]. At the same time, the frame repair and overhaul such as maintenance place cleanliness, and other environmental requirements contributed to the overall higher costs [20, 21].

In summary, the energy-saving of PMSM was about 40% over the whole life cycle of the vehicle from the point of view of comprehensive energy consumption and economic analysis. Even though the total cost of procurement and maintenance of PMSM was 17.8% higher than that of asynchronous traction motors, it was still possible to save around 11,732,400 RMB, which is 36% of the cost. Therefore, PMSM offers clear energy efficiency advantages in urban rail vehicles, reducing operating costs.



	Procurement	Frame repair	Overhaul	Total cost
AM (RMB 10,000)	144	44.088	86.4	274.488
PMSM (RMB 10,000)	161.6	60.96	100.8	323.36

Fig. 7 Expenditure on two types of motors.

4. Conclusion

This study explored the energy efficiency analysis of PMSM compared to asynchronous traction motors over the whole life cycle of urban rail vehicles, using a permanent magnet vehicle on a ground line as an example. The study concluded with the following main findings and contributions:

1. Based on the actual vehicle operation data, we established a reliable model for vehicle energy consumption that applies to this line. The full life cycle energy consumption of the permanent magnet vehicle of approximately 29,062.24 MWh was calculated. Additionally, the energy consumption characteristics and energy-saving mechanisms of the PM vehicle during the four phases of individual acceleration, uniform speed, braking, and stopping were analyzed.

2. A comparative analysis of PMSM and AM vehicles, taking into account energy consumption and economic costs, indicated that although the procurement operation and maintenance costs of PMSM are higher than those of AM throughout the vehicles' life cycle, vehicle with PMSM have higher energy efficiency and lower economic costs. The energy consumption and costs of PM vehicles are saved by 40% and 36%, respectively. Such values indicated that vehicles with PMSM are more energy-efficient and cost-effective.

3. Finally, this study provided a reference and basis for improving energy efficiency, saving energy, and reducing emissions of urban rail vehicles. It also offered data support for optimizing and controlling vehicle energy.

5. Limitations and Future Research

This study only considers the permanent magnet vehicles of one metro line as an example. It does not take into account the differences of other lines or the effects of seasonal changes and other factors on the vehicles with PMSM. It is important to note that this approach may have some limitations.

In the future, the collection and analysis of vehicle operation data from different lines and environments to establish a more general and perfect energy consumption model should be studied. Such activities would enable the carrying out of comprehensive and in-depth energy efficiency analysis and comparison, providing more effective solutions for the energy-saving technology of urban rail vehicles.

6. Acknowledgement

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Suggestions of water-saving measures: A Case Study of a University in southern China

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บทคัดย่อ ทรัพยากรน้ำเป็นหนึ่งในองค์ประกอบสำคัญของการพัฒนาที่ยั่งยืนระดับโลก อย่างไรก็ตาม ปัจจุบันทรัพยากรน้ำกำลังเผชิญกับความท้าทายร้ายแรงทั่วโลก ซึ่งรวมถึงการขาดแคลนน้ำ มลพิษทางน้ำ และอุปสงค์และอุปทานที่ไม่สมดุล มาตรการอนุรักษ์น้ำถือเป็นประเด็นสำคัญในการแก้ปัญหาทรัพยากรน้ำทั่วโลกมาโดยตลอด บทความนี้ยกตัวอย่างมหาวิทยาลัยทางตอนใต้ของสาธารณรัฐประชาชนจีนเพื่อประเมินการใช้น้ำ บันทึกมาตรการประหยัดน้ำที่มีอยู่ และเสนอการปรับปรุงเพื่อการคุ้มครองและการใช้ทรัพยากรน้ำอย่างเป็นระบบและมีประสิทธิภาพ การศึกษานี้พบคำแนะนำที่สำคัญ เช่น การเปลี่ยนระบบประหยัดน้ำแบบแมนนวลเป็นระบบอัตโนมัติ การเพิ่มมาตรวัดน้ำระยะไกลสำหรับการตรวจจับการรั่วไหล การปรับปรุงระบบน้ำร้อน และการเพิ่มการนำน้ำฝนกลับมาใช้ใหม่เพื่อการรีไซเคิลน้ำอย่างมีประสิทธิภาพ ทั้งนี้การดำเนินการที่แนะนำสามารถประหยัดน้ำได้ไม่น้อยกว่า 30,000 ตันและค่าน้ำ 135,000 หยวนต่อปี

คำสำคัญ : การประหยัดพลังงาน, มาตรการประหยัดน้ำ, ระบบน้ำรีเคลม, เมืองฟองน้ำ, ระบบตรวจสอบ

Abstract Water resources are one of the key elements of global sustainable development. However, water resources are currently facing serious challenges worldwide, including water scarcity, water pollution, and imbalanced supply and demand. Water conservation measures have always been an important issue for solving various water resource problems worldwide. This article took a university in southern of the People's Republic of China as an example, documented existing water-saving measures, and proposed improvements for systematic and effective water resource protection and utilization. The findings were key recommendations such as replacing manual with automatic water-saving facilities, adding a remote water meter for leak detection, renovating the hot water system, enhancing rainwater reuse and improving the effective utilization of miscellaneous water systems for efficient water recycling. Among them, effective utilization of miscellaneous water can save at least 30000 tons of water and 135000 yuan per year.

Keywords Energy saving, Water-saving measures, Reclaimed water system, Sponge city, Monitoring system.

1. Introduction

Water resources are strategic natural resources that are crucial to human survival and sustainable development. Recently, Li mentioned that water resources have three special attributes, including scarcity in quantity, imbalance in distribution, and irreplaceability in use [1]. In 2022, the World Meteorological Organization pointed out that severe drought has affected regions including the United States, Europe, the Middle East, and the Yangtze River Basin in China; they are facing severe drought [2]. Shen's report also pointed out that a recent report released by the World Resources Institute showed that the world is currently facing serious water resource pressures, with approximately 4 billion people, or half of the world's population, experiencing high water scarcity for at least one month each year. It is expected that the proportion of the affected population will rise to nearly 60% by 2050. The report also calls on countries to take effective action and continuously strengthen water resource management to prevent further deterioration of water scarcity [3]. The three special attributes of water resources and the current global water resource situation make water-saving actions increasingly important and urgent. Higher education institutions, as an important member of society, should become a model of water-saving behavior. Various measures should be taken to achieve the goal of water.

Article 2.0.4 of the General code for design of building water supply and drainage and water saving stipulates conservation that the processes, equipment, appliances, and products selected for building water supply and drainage and water-saving projects shall be water-saving and energy-saving. Article 3.4.1 stipulates that water supply and use shall be installed according to the purpose of use, payment or management unit, item by item, and level by level, with measuring devices that meet the needs of use and have passed metrological verification. In contrast, article 3.4.4 Water distribution branch pipes with a water pressure greater than 0.2 MPa at the water consumption point should take pressure reducing measures and meet the requirements of the working pressure of the water equipment. Article 5.1.3 regulations: The centralized hot water supply system should be equipped with a hot water circulation system. The time for the outlet temperature of the hot water distribution point in residential buildings to reach the minimum outlet temperature should not exceed 15 seconds, and the outlet temperature of the water distribution point in public buildings should not exceed 10 seconds [4].

In addition, domestic water saving devices have more detailed parameter requirements for water-saving household water appliances, such as water-saving faucets (faucets) should have manual or automatic opening and closing and control of water flow at the outlet, the use of valve products that can achieve water-saving effects, water-saving toilets should use toilets with a one-time flushing water volume of no more than 6L, water-saving toilet flushing valves with delayed flushing, automatic closing, and flow control functions, and so on [5]. Furthermore, a case study by Muhammad suggested that 76% of the houses did not have water-saving devices. In comparison, the other 24% had water-saving devices such as dual flush toys, low flow high-efficiency faucet ethers, low flow plum fixtures, and automatic shut-off puzzles. A unit increase in water saving devices will lead to a 0.512 decrease in water consumption level [6].

Several researchers have paid attention to conserving water resources and usage. Wang et al. used a certain institution as a case study to set up a refined water use classification and metering hardware system, achieving automatic acquisition of water use data by region, floor, and functional area. A comprehensive intelligent water-saving monitoring hardware system was conducive to timely detecting water usage abnormalities, analyzing leakage phenomena, tapping the potential, and increasing the efficiency of water-saving work in public institutions [7].

Anchan and Prasad [8] suggested that a South Indian University could resolve the water scale issue by accumulating about 1,13678.9 m^3 of stormwater from a rooftop in a year and using it during the non-monsoon season. Liu and coworkers conducted a study on water-saving measures such as rainwater recycling in a Chinese university. They concluded that both water-saving and unconventional water source utilization could implemented simultaneously, resulting in (a 470,000 cubic meters reduction) of about 2.15 million yuan in water costs and reducing the operating and maintenance costs of domestic water supply and green landscape water bodies within the campus [9]. Zhang et al. proposed a long-term strategic perspective: urban recycled water should become an important aspect of the new urban water supply source. Urban recycled water irrigation for green spaces would be an important component of the urban water cycle, and the research and application of urban recycled water irrigation for green spaces will be of great significance [10]. Lu introduced the importance of the application of the Sponge City (SPC) concept as well as its problems in the building water supply and drainage design and put forward corresponding solutions hoping to help urban infrastructure construction [11]. Furthermore, an independent analysis was conducted on two cities in China as cases, and SPC measures suitable for the city were listed [12].

Zheng proposed remote control of pump room equipment through the internet or mobile internet. This system can greatly improve the management ability of urban water supply and ensure water safety, saving a lot of manpower and time [13]. The

Internet of Things was used for data analysis and visualization of the pressure data in real-time through SMS/email and provide alarms, timely detecting faults and leaks in the water supply system [14]. A leak detection system for water supply pipelines based on flow monitoring and Internet of Things technology is suitable for the timely detection of leaks in modern urban water supply systems. By installing flow meters on the inlet valves of each residential area, a total water meter, flow meter, and computer Internet of Things system for the residential area were established, and the data was summarized for analysis and detection of leaks [15]. The purpose of this study is to investigate and verify the current water use situation of the university, list the water-saving measures currently implemented by the university, and analyze and propose improvement suggestions for water-saving measures to achieve systematic and effective protection and utilization of water resources.

2. Materials and Methods

This study took a university located in southern China as an example. The existing data on water appliances and equipment for some typical buildings on the campus are shown in Table 1.

Table.1 Water appliances and equipment.

Building Name	**Appliances/ Equipment**	**Number**
Teaching Building	Faucet	141
	Toilet	203
	Urinal	108
Phase I &II Student Dormitories	Faucet	2,196
	Toilet	1,574
	Urinal	18
	Shower	1,574
Business Faculty	Faucet	63
	Toilet	95
	Urinal	34
Faculty of Architecture and Design	Faucet	123
	Toilet	99
	Urinal	48
Athletics Field	Faucet	39
	Toilet	52
	Urinal	24
	Shower	42

After on-site verification, all water-consuming equipment and sanitary ware listed in Table 1 were water-saving sanitary appliances, faucets, etc., all complied with the current industry standard, the domestic water saving devices CJ164-2002, and used first-level water efficiency products. The toilet adopted a water-saving toilet with a flushing capacity of no more than 6 L/time (using a 3/6 L double shift or siphon type), the urinal adopted an induction flushing valve, and most washbasin faucets used induction faucets. All faucets were made of ceramic pieces with good sealing performance and durability. However, in actual use, there were cases where manual faucets were not turned off in a timely manner.

The setting of water meters on the campus is as follows:

Teaching and office buildings: A water meter was installed at the main inlet pipe only, which had a remote data transmission function.

Dormitory building: A main water meter was installed at the main inlet pipe, and a separate water meter was installed in each dormitory room. The water meter had a remote data transmission function.

Grading measurement basically met the requirements of the general code for the design of building water supply and drainage. The schematic diagram of the water supply metering system in the dormitory building was shown in Figure 1. (taking the Phase II Student Apartments as an example).

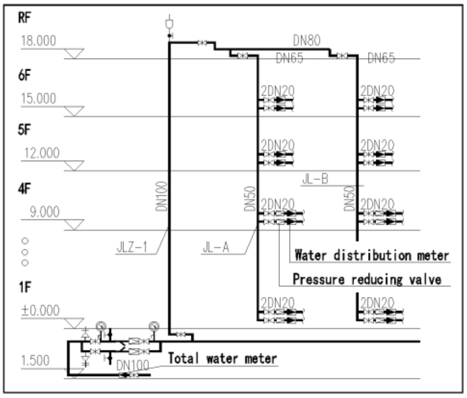

Fig. 1 The schematic diagram of the water supply system in the dormitory building.

From Figure 1, The water supply system has installed water meters according to usage, payment or management unit, item by item, and level by level. And it could be seen that the water supply method for the dormitory building was top-down, so a pressure reducing valve was installed on the floors with higher pressure to adjust the pressure to below 0.2. This measure met regulatory requirements, and appropriate water supply pressure had a positive impact on the service life of pipelines and valves and unnecessary water resource waste.

From the hot water system diagram of the dormitory building shown in Figure 2, it could be understood that the system was equipped with three thermometers, T1, T2, and T3, respectively, on the water tank, hot water supply pipeline, and hot water return pipeline. Such arrangement allowed the system to operate corresponding equipment based on the detected temperature difference, such as:

- When the thermometer T1 ≤ 55 ℃, turned on the air source heat pump hot water unit, which heats the cold water.
- When the thermometer T2-T3 ≤ 2 ℃or T1 ≥ 60 ℃, turned off the air source heat pump hot water unit.
- When the temperature gauge T1-T3 ≥ 10 ℃, opened the return water solenoid valve on the T3 side.

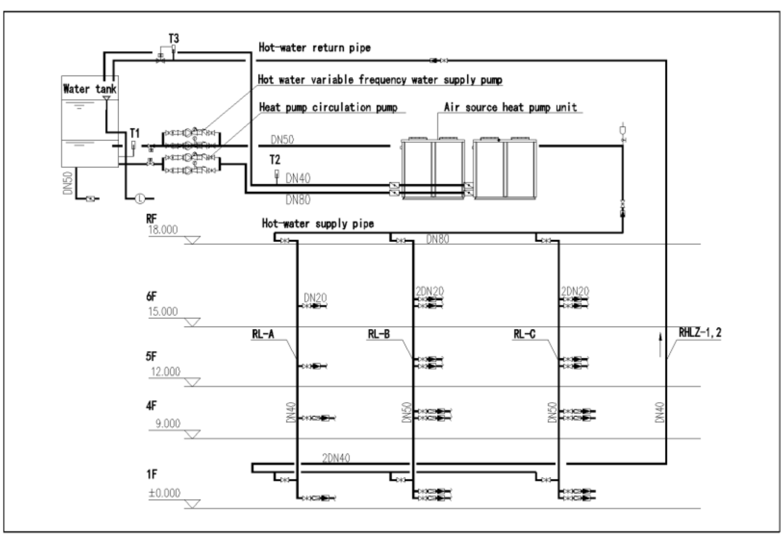

Fig. 2 Schematic diagram of the hot water system in the dormitory building.

Through continuous observation of the operation of the hot water system in the Phase I student dormitories (completed and put into use in 2015) and Phase II student dormitories (gradually completed and put into use in 2018), the average hot water outlet speed in Phase II student dormitories was about 15 seconds, which basically met the standard requirements. However, the average hot water outlet speed in the Phase I student dormitories was about 30 seconds. The reasons for the slow outlet speed were analyzed as follows:

1). The branch pipe at the end of the dormitory was not included in the return water pipeline, and the distance between the branch pipes was too long. When using hot water, it was necessary to drain this part of the cold water before hot water could be produced.

2). The setting position of some T2/T3 thermometers was not reasonable enough; for example, T3 was set at a hotter position in the return pipe, but in reality, the temperature inside the return pipe was already too low, or the thermometer had become invalid and had not been replaced.

3). Due to the age, some insulation cotton for pipelines had aged, and replacement was needed.

The university had done the following work in rainwater recycling and Sponge City construction:

1). Some buildings had rooftop gardens, and some pedestrian paths used permeable bricks.

2). A central lake had been set up in the center of the campus, which collected the surrounding mountains and rivers, natural rainwater, and rainwater from various buildings through outdoor rainwater pipes into the lake. A regulating weir had been set up and closed during the dry season to ensure the water level of the central lake. During the rainy season, the regulating weir discharged floodwaters based on the water level.

3). The newly built library (completed and put into use in 2023) was equipped with a rainwater recovery system, which collected rainwater from the buildings and the central lake and then lifted to the machine room for further treatment by a rainwater lift pump. The treated water was used for green irrigation.

4). A miscellaneous water treatment station had been set up to treat miscellaneous water for green irrigation, and miscellaneous water irrigation pipelines had been gradually built from 2010 to the present (as shown in Figure 3.).

However, there were the following issues with rainwater recycling and Sponge City construction:

1). Due to construction quality issues, the rainwater recovery system in the library could not be put into normal use. The reason was that the liquid level meter was malfunctioning, unable to automatically replenish water, supplied water, and the outdoor landscape pool was leaking, unable to store water.

2). Due to the gradual construction of miscellaneous water pipelines according to engineering projects, the quality of the pipelines varies, and there was a phenomenon of water leakage.

3). At present, the water source of the miscellaneous water pipeline was the river water around the campus rather than the miscellaneous water within the campus.

4). The campus green area was about 180,519 m^2, and the water treatment capacity of the miscellaneous water pump room (about 100 Ton/day) was not enough to support the one-time green irrigation water for the whole school in the dry season. The water outlet pressure (0.4 MPa) could not reach the same irrigation for the whole school (which can be divided into zones for irrigation).

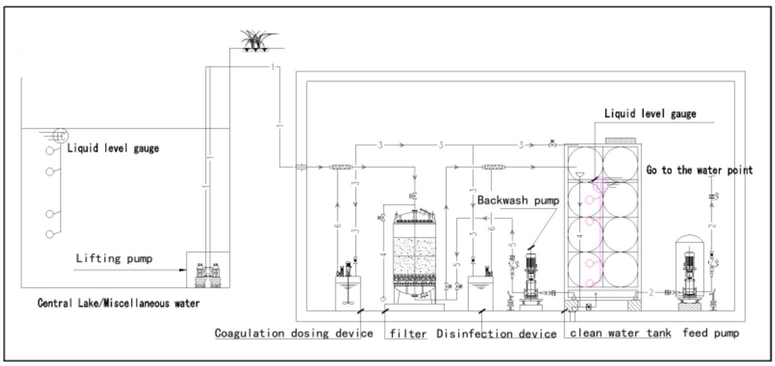

Fig. 3 Rainwater collection and reuse/miscellaneous water use process diagram.

The university built a smart water management platform in 2020 (as shown in Figure 4.); this platform combined the remote water meters installed at the entrances of various buildings, which were used for daily water supply monitoring. It could timely monitor the total water consumption and detect abnormal water use, pressure anomalies, and the range of water supply leaks.

After the smart water management platform was put into use in 2020, a total of 28 pipeline leaks were detected by the platform in 2021 (as presented in table 2), and timely repairs were made.

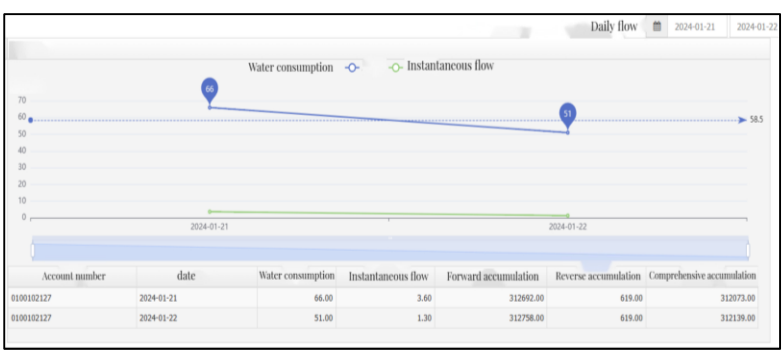

Fig. 4 Schematic diagram of smart water management platform (from the computer monitor)

3. Results and discussion

Based on the above analysis of the water-saving measures of the university, the following improvements can be made in terms of water-saving measures:

1). Although all water end devices in the school, such as faucets, toilets, and urinals, were already water-saving devices, not all water-saving devices are automatic, some of which are manual. Due to personal usage habits, some personnel might keep manual water-saving devices on for a long time when using them. It was recommended to gradually change manual water-saving devices to automatic water-saving devices (especially faucets) in the next stage; this would further improve the water-saving effect.

Table. 2 Campus Pipeline Maintenance Record (Partially) in 2021.

Serial number	**Discovery (month, date)**	**Leak location and quantity**	**Repair (month, date)**
1	2.23	Orchid Student Apartment 30m^3/day	2.27
2	3.15	Orchid Student Apartment 30m^3/day	3.18
3	4.22	Business Faculty 130m^3/day	4.25
4	5.25	Plum Blossom Student Apartment 30m^3/day	5.30
5	6.16	Plum Blossom Student Apartment 40m^3/day	6.20
6	7.15	Plum Blossom Student Apartment 80m^3/day	7.20
7	9.2	Plum Blossom Student Apartment 60m^3/day	9.6
8	10.15	Plum Blossom Student Apartment 40m^3/day	10.20
9	11.11	Main water supply pipeline 200m^3/hour	11.11
10	11.25	Orchid Student Apartment 10m^3/day	11.29

2). At present, the school had installed a Campus water inlet meter（M1) on the campus main water supply pipeline, water inlet sub meters (e.g., M2, M3) in public areas such as teaching buildings, Athletics Field (as shown in Figure 5.), and set up a remote smart water management platform, If the reading of the M2 was much higher than usual, it could quickly determine the presence of water leakage behind the M2. But if there was a significant difference in the reading between the M1 and the sum of all sub meters (i.e., M2+M3+...+Mn), although it could be determined that there was a leakage, it was not known where the leakage point was (i.e., the pipeline between M1 water meter and M2 water meter).

It was recommended to select several locations between the main and sub meters to install remote water meters for intermediate inspection, which would lock the leakage point more quickly and reduce the time for leak detection. The significance of this suggestion was significant, as we could see from the role of our own smart water management platform.

Before the establishment of a smart water management platform, campus managers only judged whether there was a water leakage phenomenon based on the difference between the readings of the only main water meter on the campus pipeline and the manual reading of the sub water meter inside the campus. Often, when making a water leakage judgment, it had been a long time since the leakage occurred, and the amount of water leakage could not be estimated. The maintenance time was also greatly prolonged, resulting in the loss of water resources; After building and putting into use the smart water management platform, 28 leaks were promptly discovered and repaired in 2021 alone.

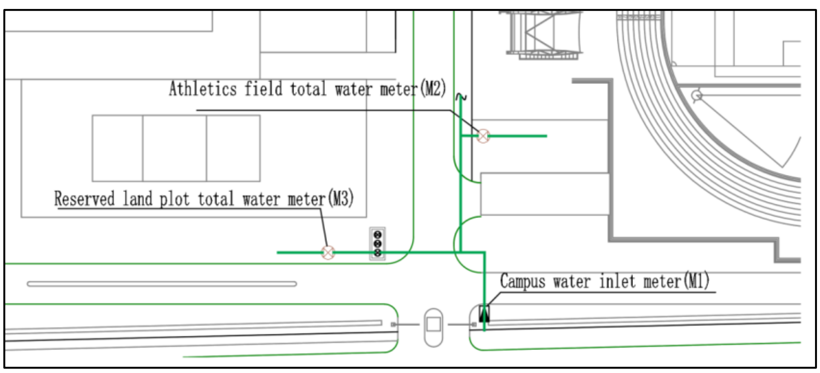

Fig. 5 Schematic diagram of campus outdoor water meter (partially).

Assuming: that without the installation of a smart water management platform, it took ten days to detect water leakage. At present, the water fee in the city was 4.5 RMB/ton; therefore, from Table 2. it could be estimated that the amount of water leakage for these ten times was: (30+30+130+30+40+80+60+40+10) m^3/day x 10 days + 200 m^3/hour x 24 hours x 10 days = 52,500m3. and, 52,500 m^3 x 4.5 RMB/ton = 236,250 RMB.

However, because a smart water management system had been installed, these wastes have been avoided. Similarly, installing a remote water meter on the pipeline between M1 and each Mn and incorporating it into the existing smart water management system would greatly shorten the time for water leakage detection, thus avoiding waste.

3). For dormitories with a hot water system with a hot water outlet speed greater than 15S, it was recommended to carry out pipeline renovation by extending the return water pipe section as much as possible to the end of the water supply, reducing the time for cold water release, and finding a reasonable T1, T2, T3 thermometer position, and repair damaged pipeline insulation facilities.

4). Water leakage reduction could be achieved through the repair of the rainwater recovery system, including the water level gauge, landscape pool, and miscellaneous water supply pipeline.

5). The laying of roads on the campus with permeable bricks and the establishment of more rooftop gardens should be gradually undertaken.

6). Miscellaneous water pipelines could be laid to the central lake of the campus, and the miscellaneous water source could be changed to the central lake of the campus.

7). The biological habits of various plants on campus could be familiarized with, and irrigation plans for miscellaneous water could be developed based on species, zones, and seasons. Humidity detectors in the soil could be set up to transmit data to the miscellaneous water irrigation system, ensuring irrigation only when necessary and maximizing the use of the miscellaneous water irrigation system.

Assuming: the usage time of the miscellaneous water system is 300 days in a year, the water resources and costs that would be saved in a year were 300day x 100 ton =30,000 ton, then, 30,000 ton x 4.5 RMB/ton = 135,000 RMB.

4. Conclusion

This study analyzed the water-saving measures and shortcomings implemented by a university in southern China, and the following conclusions could be drawn.

1). By replacing existing manual water-saving facilities with automatic water-saving facilities, water could be effectively saved.

2). Based on the existing leakage control achievements of smart water management, remote water meters between the main water supply meters and the sub water supply meters could quickly identify the leaking pipe section and perform rapid pipeline maintenance, thereby saving water, were recommended to install.

3). The reduction of cold water loss and acceleration of hot water discharge speed could be achieved by renovating the hot water system

4). The rainwater reuse system was repaired, and the construction of sponge cities was improved to effectively achieve the recycling and utilization of rainwater and miscellaneous water. Simultaneously, the reasonable use of miscellaneous water systems could save at least 30,000 tons of water consumption and 135,000 RMB of investment annually.

5. Limitations

This study was conducted as a case study; Therefore, certain shortages or restrictions will be as follows.

1) In order to renovate existing water-saving equipment, pipelines, and systems, it was necessary to comprehensively consider the investment cost, return period, and implementation time of the renovation (without affecting normal teaching activities).

2) The overall energy-saving and economic benefits generated by some water-saving renovations (such as replacing water-saving equipment, renovating hot water systems, and continuing the construction of sponge cities) still need to be further demonstrated through a period of practical application (at least one year) in actual use. The water-saving benefits will be influenced by factors such as user energy-saving awareness and management level.

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Physico-Mechanical Properties of Mortar in Place of Fine Aggregate with Multi-Layer Laminated Packaging

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Abstract The purpose of this experimental study is to investigate the properties of mortar when mixed with multi-layer laminated scrap. By investigating the physical and mechanical properties of multi-layer laminated scrap substituting sand in different combination ratios. It was evaluated to measure water demand, absorption, and compressive strength, with the goal of using multi-layer laminated packaging leftovers as construction materials to further decrease environmental problems. Each specimen, which measured 50 mm by 50 mm by 50 mm, was used to create mortar. A volumetric mixture of cement and fine aggregate was utilized, with a ratio of 1:2.75 by weight. Subsequently, the percentage replacement of the multi-layer laminated scrap with fine aggregate was recorded as follows: 0%, 36%, 64%, and 100%. Then, a pavement brick mold was used to form pavement bricks mixed with multi-layer laminated scrap compare with plain pavement bricks. Compressive strength and water absorption were tested. Each mixture, including the control, had three replications, and the compressive strength was measured at 1, 3, 7, 14, 21, and 28 days of curing. The findings for water absorption showed that when employing more multi-layer laminated scrap, the amount of water used in molding increases. Although water demand reduced, flow values remained within the typical range of 110±5%. After 28 days of specimen aging, the compressive strength of mortar when mixed with multi-layer laminated scrap was 271, 247, 170, and 120 ksc, respectively. The compressive strength of the varied ratios dropped as the amount of multi-layer laminated scrap in the mix ratio increased.

Keywords: Multi-layer laminated scrap, Compressive strength, Water absorption

1. Introduction

Plastic is a material that is widely used and is considered one of the most important inventions of the 20th century. The development of plastic production technology made it possible to create packaging with several layers that combine various materials into a single structure [1]. Every year, more than 25 million tons of plastic waste are generated globally [2]. As a result, the industry was able to integrate functional qualities such as barriers, mechanical strength, and heat tolerance while lowering the average thickness of packaging materials using multi-material plastic [3]. Because of this, multilayer plastic packaging became crucial for a number of applications, preventing both excessive material consumption and the associated expenses as well as inadequate use and product losses [4]. These multilayer, multi-material films and sheets are made by co-extrusion or lamination techniques using a variety of polymers, such as polyesters like PET and PLA, polyolefins like PP and PE, and chemical variants like HDPE, LDPE, LLDPE, and OPP [5, 6]. Robertson (2016) states that sufficient strength is necessary for packaging design in order to contain and resist impacts [7]. Furthermore, sealing performance is crucial for protecting the goods from deterioration. Thus, for packing to work properly, the items must be shielded from abrasion, moisture, oxygen, light, odor, flavor, stiffness, pliability, and heat resistance characteristics [8, 9]. These days, plastic trash poses a major environmental risk to contemporary civilization due to its composition of multiple hazardous compounds, which can contaminate land, water, and air if improperly handled or processed [10]. Additionally, if mixed with soil, plastic waste might slow down the rate of percolation, which will reduce the fertility of the soil [11]. Since the recycling industry is unable to recognize, classify, and separate the various layers using the present standard technologies, multilayer plastic recycling is often complicated [12]. As a result, there have been numerous initiatives around the world, particularly in wealthy countries, to transform plastic trash into valuable items [13]. The only way to lessen environmental problems brought on by trash disposal and the usage of non-renewable resources is through recycling.

Nowadays, most research focuses on the potential for recycling these wastes into concrete in situations where the strength of the concrete isn't the primary factor being examined, such large volumes of PCC (Portland Cement Concrete) being used for pavements [14]. Numerous writers investigated the substitution of aggregates with plastic foams and found certain problems, such as buoyancy, deformability, water absorption, and aggregate proportioning [15]. A significant amount of research has already been done on the use of plastic waste, such as glass reinforced plastic (GRP) [16], polycarbonate [17], polyurethane foam [18], and polypropylene fiber [19], as an aggregate, filler, or fiber in the preparation of concrete. Other examples of plastic waste include polyethylene terephthalate (PET) bottles [20], high density polyethylene (HDPE) [21], and recycled plastic waste [22]. A growing number of researchers are looking into the possibility of using waste plastic materials as aggregate replacement in mortar or concrete due to this and the desire to reduce the use of natural resources in the construction industry, with a focus on the amount of land required for concrete aggregates. Lightweight aggregates were created in this effort to replace sand in mortars. The "end of waste materials" were acquired by the separation and mechanical recycling of small-sized post-consumer packaging films [23].

Based on the feasibility of recycling multi-layer laminated packaging (MP) has been utilized in scrap form to create new materials as a sand replacement material. In this investigation, MP scrap has been used in various ratios to substitute sand in the concrete mixture; the substitution was made by volume rather than weight. Because aggregate materials, such as sand and multi-layer laminated packaging scrap, range greatly in their bulk densities based on factors like compaction, moisture content, and other factors, volume specification takes these differences into consideration. The results of many testing have been presented. Physico-mechanical properties including compressive strength, mortar test, and water absorption are all considered throughout the inspection.

2. Materials and methods

The use of MP in place of fine aggregate in the mortar production process has, however, received little research. Al-Manaseer and Dalal [24] conducted the first studies on the impact of replacing fine aggregate in concrete with plastic particles, examining the effect of increasing the amount of angular waste plastic particles on cylinder strength for three different water-to-binder ratios. Poor bonding between the plastic and cement paste was discovered to be the cause of the diminishing compressive strength observed with an increase in the amount of plastic aggregate. During the compressive testing of the concrete, the plastic was able to pull out instead of splitting in tension. The materials used in this study to manufacture the cement mortar were presenter into 2 parts as follows:

Part 1: Material preparation and testing of basic material qualities such as specific gravity, absorption, mixed design and weight unit. The materials utilized in the research include:

1.1 Type I ordinary Portland cement is the most widely used type of cement. To cement, numerous tests were carried out, among of which include standard consistency tests, setting time tests, etc.

1.2 The manufacturer's multi-layer laminated packaging was sifted using a standard number 4 sieve to remove large particle contaminants. Fine aggregate sizes were then selected for use in mortar testing by passing through sieve no. 16 and retaining sieve no. 100. The water content was then calculated based on ASTM C230 criteria. Sample of multi-layer laminated scrap before and after sizing are displayed in Fig.1.

(a)

(b)

Fig.1 Sample of multi-layer laminated scrap (a) before, and (b) after sizing

1.3 Fine Aggregate: Sand is typically used as the fine aggregate. A minimum void ratio should be achieved by the sand particles; a greater void ratio necessitates the use of more mixing water.

1.4 Water: Water from the Metropolitan Water Supply that complies with ASTM C156 – 03 for water for concreting and curing materials is available.

Multi-layer laminated scrap and river sand were mixed in a container using a stirring rod. The trial-and-error method was used to determine the amount of multi-layer laminated scrap and sand required to manufacture one tile or block. This takes into consideration forecasting and testing the sand- to- multi- layer laminated scrap ratio before to use. Depending on the volume of aggregates, a cement to fine aggregate ratio of 1: 2. 75 by weight was permitted. Following that, the following percentages of fine aggregate were used to replace sand by multi-layer laminated scrap as: 0% , 36% , 64% , and 100% . The substitution of multi-layer laminated waste in mortar may result in a number of expected outcomes. Regarding the potential effects of this approach, the following expectations and presumptions exist by lowering the quantity of plastic trash that ends up in landfills or the environment, adding plastic scrap to mortar can help create a more sustainable building sector. Sand and gravel are examples of natural resources that can be preserved by partially substituting plastic scrap for traditional aggregate materials in mortar. Depending on the kind and quantity of plastic scrap utilized, the mortar's longevity, flexural strength, and compressive strength may all be impacted by its presence.

Part 2: Testing to estimate the water requirements in the mortar mixture in accordance with the ASTM C-230 standard, which is a flow table test to measure the flow of cement mortar. Determine the amount of water used to test for percent flow. The amount of water is obtained from the shaping of sidewalk bricks. Consider the mixing ratio that was evaluated for flow spread. Molded into mortar test blocks for further compressive strength testing, which will be described and demonstrated in the mixing details later. The amount of multi-layer laminated scraps substituting sand in various mixing ratios is tested for compressive strength using ASTM C109/C109M criteria at ages 1, 3, 7, 14, 21, and 28 days. The test ratio of cement, sand, and multi- layer laminated scrap, which results in three samples of compressive strength testing in each age. Mortar test findings are used to compare and discover patterns in subsequent strength development. The second section of the ASTM C230 test results are being examined to identify the volume of multi- layer laminate scrap, the water requirements when replacing sand with multi- layer laminated scrap, and the mixing ratio values for control. Mortar flow and the mix ratio that produces the maximum compressive strength.

3. Results and discussion

Physical properties

The following are the test results for physical properties of materials preparation, such as specific gravity, absorption, analysis of mixed sizes, and weight unit.

1. The average specific gravity of Portland cement Type 1 according to the ASTM C188 standard is 3.17.

2. According to ASTM C 128, the average value for multi- layer laminated scraps is 0.77.

3. According to the ASTM C 128 standard, the specific gravity of sand averaged 2. 53, with a percentage of absorption of 1. 42 percent while the average unit weight of sand,

according to the ASTM C29 standard, is 1,620 kg/m^3.

For example to prepare materials, the ratio of C: fine aggregate = 1:2.75 by weight when fine aggregate included sand and MP,

In M-1 mix; MP = 0%, so when we need weight of sand = 2,750 kg, volume of sand will be 1.09 m^3 (2,750/(2.53x1000)).

In M-2 mix; MP = 36%, we need volume of MP which replace sand = 0.36x1.09 = 0.39 m^3, so weight of MP = 0.77x0.39 = 0.30 kg.

Mortar Test Results

Water absorption is one of the physical attributes that present performances that are currently being discussed among the authors in the literature, with aspects and scenarios being thoroughly explored [25]. The flow table test is used to determine the water requirements of mortar mixtures in accordance with ASTM C-230 recommendations (Fig.2). The molding yielded information about the fluidity of cement mortar, the volume of water necessary to determine flow spread, and the amount of water. The mixture ratio tested for flow spread was then applied, followed by an evaluation of compressive strength using mortar blocks (Fig.3). Afterwards, the researcher used a flow value of 110±5 for standard mortar while other sample use w/c ratio as shown in Table 1 to make pavement bricks rather than cubes since the conventional flow value causes layers of segregation between the sand and laminated packaging scraps rather than homogeneity. The amount of water was determined by testing the paving bricks, as seen in Fig.4 When using more multi-layer laminated scrap, the amount of water utilized in molding increases. The water demand decreased, but the flow value stayed within the normal range of 110±5%. The compressive strength of the flow test sample cast into the mortar test slump was tested using ASTM C109/C109M standards, and the results are also shown in Table 1. According to Alhasanat et al. [26], the addition of fine recycled plastic particles improves workability, while the addition of fibers and coarse aggregates reduces it. Based on an analysis of the literature on the influence of PP, PE, and PVA fibers, Pakravan et al. [27] concluded that workability is not extremely sensitive to fiber type.

Fig.2 Flow table test according to ASTM C230

Fig.3 Samples of mortar for compressive strength tested using ASTM C109/C109M

Fig.4 Samples of plain pavement bricks and pavement bricks mixed with multi-layer laminated scrap.

The experiment's results revealed that conventional mortar and mortar blended with additional layers of laminated packaging debris required less water due to the sample blocks' reduced water absorption. Almeshal et al. [28] indicate that water absorption increases as the sand-to-plastic replacement ratio increases. This is due to increased porosity in the cementitious matrix. In reality, increasing the size of plastic/rubber particles, the quantity of aggregate and fibers, and the w/c ratio all have an effect on water absorption. The preliminary characteristics testing found that the sand's water absorption values differed from those of multi-layer laminated waste. Even though some water may adhere to the surface of multi-layered laminated scrap. The water utilized in molding has a flow value of 110±5%, which is within the standard range. As a result, the potential use of plastic waste in building would open up a new avenue for managing these plastic wastes and reducing their negative environmental impact. Unlike other potential applications for plastic waste, using plastic waste for construction would pave the door for the usage of a huge volume of plastic trash [29].

Table.1 the flow test combination results for ASTM C230 and compressive strength test results for ASTM C109/C109M.

Sample No.	C	W/C	S (%)	MP (%)	ASTM C230 (%)	Compressive Strength Test, ksc. (days)					
						1	3	7	14	21	28
M-1	1	0.77	100	0	110	103	171	219	241	254	271
M-2	1	0.76	36	64	107	113	202	209	225	242	247
M-3	1	0.75	64	36	105	78	105	125	142	161	170
M-4	1	0.74	0	100	103	79	86	88	105	115	120

Note: C = Cement; W/C = Water to cement ratio; S = Sand; MP = Multi-layer laminated packaging

Cement:Fine aggregate ratio was set as 1:2.75 by weight (Fine aggregate included S and MP)

Overall, the compressive strength of all types of waste-containing mortars reduced as compared to the reference mortar. Fig.5 depicts the mortar's compressive strength test results. It was discovered that the compressive strength of ordinary mortar and mortar mixed with multi-layer laminated scraps increased with mortar curing time in each mixture. Furthermore, it was discovered that as more multi-layer laminated scraps were replaced, the compressive strength declined when the porosity of the sample appears to have risen. Although mechanical values decrease with more multi-layer laminated scraps, they remain sufficient for non-bearing concrete buildings. As a result, the potential utilization of waste materials will enhance the sustainability of construction processes and practices. The sustainable use of multi-layer laminated scraps for building also has economic benefits. Compared to other types of plastic waste, the usage of low-density polyethylene (LDPE) and high-density polyethylene (HDPE) plastics has been found to be the most promising in asphalt mixtures [30, 31].

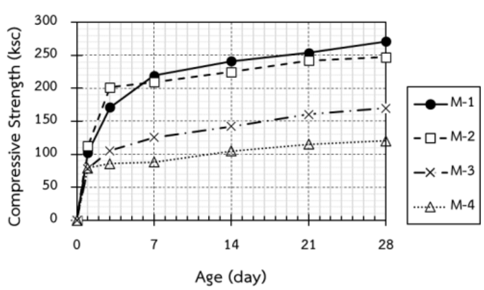

Fig.5 Improving of the compressive strength of mortar per replacement of multi-layer laminated scrap.

The weight of the sample is depicted in Fig.6, which indicates that the relationship between the weight of the sample and compressive strength tends to rise as the sample weight increases. Particularly, because of the pozzolanic reaction, the fineness of fine aggregates, and the acceleration of cement hydration, there is a discernible rise in the mortar's compressive strength, especially during the early curing days at normal temperatures. Concrete loses density and compressive strength when waste plastic is substituted volumetrically for sand; the strength losses increase with higher replacement ratios. This might be the result of a weak connection between the plastic and the surrounding matrix, an accumulation of water because the hydrophobic plastic surface increases gaps, or a breakdown of the plastic under tension [32]. Then, without being activated, MP can only function as inert filler. Greater compressive strength is correlated with increased weight. A high weight will result in a low porosity sample, which will have less space inside the sample and be stronger. The test results, which were plotted on a normal probability paper, demonstrated a modest improvement in the material's compressive strength relative to the weight of the concrete. It follows that the sample's weight should be unable to withstand significant force. When examining the test findings and force development curves, they will be consistent. The results from the average absorption of the sample from Fig.7, which shows the absorption value of the sample and indicates the gaps in the test sample that expand when more multi-layer laminate scraps are mixed. This increases the absorption value, and the data is consistent in terms of absorption, weight obtained, and test sample compressive strength. The cast specimen was subjected to a water absorption test in order to better understand its properties. Water absorption reached a maximum of 21.65% in the 100 percent of multi-layer laminated scrap replacement (M-4), and it was as low as 8.43% in the brick with the 36 percent of multi-layer laminated scrap mix (M-2) while the water absorption of the conventional bricks (M-1) was 6.56%. Several investigations have demonstrated that plastic sand bricks with specific plastic to sand ratios are a viable non-bearing alternative to conventional bricks and concrete blocks, particularly in terms of compressive strength, maximum load crushing, water absorption, and efflorescence testing [33, 34].

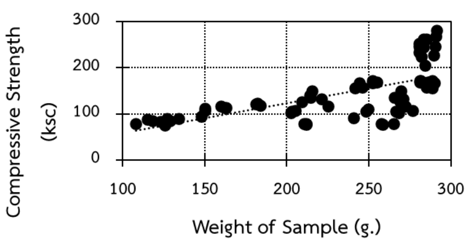

Fig..6 Relationship between sample weight and compressive strength

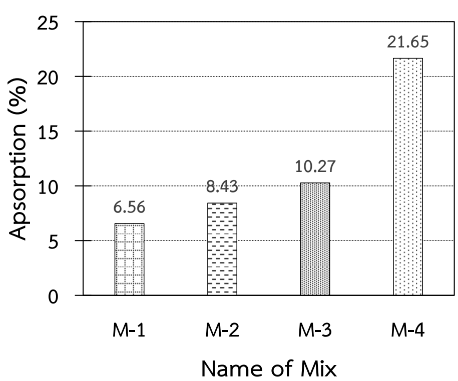

Fig.7 Absorption value of the sample

However, according to the reviewed literature, there are no studies on environmental analyses, such as life cycle assessment (LCA) based on material flow analysis of plastic waste concrete. Several publications emphasize the need to conduct environmental evaluations about plastic waste concrete [35, 36].

4. Conclusion and suggestions

Plastics play an essential part in modern civilization and are utilized in a variety of applications due to their low cost, simplicity of manufacture, and appealing properties. Unfortunately, because plastic garbage is biodegradable, it poses significant environmental concerns to modern society. The percentage of recycled plastic can be enhanced by converting discarded plastic into mortar and concrete products appropriate for residential and other construction projects. In this investigation, multi-layer laminated scrap was employed instead of cement mixed with river sand to make mortar. Replacing cement with plastic trash will help to decrease environmental issues related with both plastic waste disposal and the cement industry itself. The preliminary results of this study show that MP scrap can be blended with variable amounts of sand to create a feasible composite for usage as high-strength construction materials and concrete alternatives. Based on the findings of all research, the following conclusions can be drawn.

1. Flow determination tests with pavement brick molding data reveal that water demand decreases as the amount of MP scrap increases. ASTM C-230 testing results indicate a range of 110±5% for standard mortar. The range of W/C ratio was found between 0.76-0.74 which also

trend to decrease as the amount of MP scrap increases.

2. The outcomes of the tests verify that MP can be utilized in place of fine aggregate. It was found that the weight of the sample reduced while the absorption value increased when the number of MP scraps increased. Nevertheless, the sample's porosity causes its compressive strength to decrease, and as porosity increases, so does the impact of moisture content on compressive strength. There is minimal development in compression strength, despite a rise in compressive strength.

3. The weight of the lightweight sample block clearly demonstrates the benefits of employing multi- layer laminated debris in place of fine aggregate. So, it can be used as an alternative in places that do not require compression, reducing the strain on the structure in another way.

Substituting plastic trash for cement will help to lessen the environmental impact of both plastic waste disposal and cement manufacturing. Finally, a more extensive economic and lifetime analysis is required to establish the cost of this option against concrete, as well as its overall environmental impact. In the future, plastic can be used to replace gravel and cement in the construction of plastic roads, which are popular in some parts of the world. As a result, it can also be utilized to expand macro- scale building, which will gain traction as the globe moves toward a plastic-free zone. Under this scenario, the product might prove to be a viable substitute for existing commercial products, as it would be environmentally friendly and ensure intriguing physical attributes. The gathering of plastic waste prior to recycling is one of the main limitations on its application. Plastic waste are usually contaminated when they are gathered from different streams where they are created with different kinds of plastics and other pollutants. Unlike building materials like steel, it is composed of several plastic grades and types, which could lead to a non-isotropic performance when utilized in construction. However, future research is required to address a number of issues, including handling different plastic types and proportions, chemical properties, comprehending the plastic sand bricks' long- term performance, addressing the flammability and fire resistance of the material, and heat conductivity and potentially the acoustic characteristics of the finished product.

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รายนามผู้ทรงคุณวุฒิประเมินบทความ

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คำแนะนำสำหรับผู้เขียน

วารสาร SAU JOURNAL OF SCIENCE & TECHNOLOGY ตีพิมพ์ปีละ 2 ฉบับ โดยมหาวิทยาลัยเอเชียอาคเนย์ บทความที่พิจารณาตีพิมพ์ในวารสารนี้จะต้องเป็นบทความที่ไม่เคยตีพิมพ์เผยแพร่ในวารสารใดมาก่อน และไม่อยู่ในการพิจารณาของวารสารอื่นๆ เรื่องที่จะตีพิมพ์จะต้องได้รับการกลั่นกรองจากผู้ทรงคุณวุฒิในสาขาที่เกี่ยวข้องอย่างน้อย 2 คน กองบรรณาธิการอาจให้ผู้เขียนปรับปรุงให้เหมาะสมยิ่งขึ้นและทรงไว้ซึ่งสิทธิ์ในการตัดสินตีพิมพ์หรือไม่ก็ได้

ประเภทผลงานที่ตีพิมพ์

1. บทความวิจัย (Research articles) เป็นผลงานที่เตรียมจากข้อมูลที่ผู้เขียน หรือทีมงานผู้เขียนได้ค้นคว้าวิจัยด้วยตนเอง
2. บทความวิชาการ (Academic articles) อาจแยกเป็นบทความปริทรรศน์ (Review articles) บทความเทคนิค (Technical article) เรียบเรียงจากการสืบค้น ตรวจสอบเอกสารวิชาการในสาขานั้นๆ และบทความพิเศษ (Special articles) เสนอความรู้ทั่วๆไปในด้านวิทยาศาสตร์และเทคโนโลยี

การเตรียมต้นฉบับบทความ

บทความหรือผลงานวิจัยที่นำเสนออาจอยู่ในรูปแบบภาษาไทยหรือภาษาอังกฤษ โดยจัดพิมพ์ด้วยโปรแกรมเวิร์ดโปรเซสเซอร์ ภายใต้ระบบปฏิบัติการวินโดว์ สำหรับตาราง แผนภาพและภาพประกอบในส่วนของต้นฉบับจะต้องตามรูปแบบที่กำหนดเพื่อให้พร้อมตีพิมพ์ได้ทันที (Camera ready) ต้นแบบสำหรับบทความสามารถดาวน์โหลดได้จากเว็บไซต์ saujournalst.sau.ac.th

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ต้นฉบับสำหรับบทความที่เขียนเป็นภาษาไทยสำหรับวารสาร

SAU JOURNAL OF SCIENCE & TECHNOLOGY

ชื่อบทความ
Title of the Paper

ชื่อ-นามสกุล ผู้ประพันธ์ (ภาษาไทย)

ชื่อ-นามสกุล ผู้ประพันธ์ (ภาษาอังกฤษ)

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บทคัดย่อ นี่คือต้นแบบสำหรับบทความของคุณเพื่อเสนอพิจารณาตีพิมพ์ในวารสาร SAU JOURNAL OF SCIENCE & TECHNOLOGY จัดพิมพ์ด้วย Microsoft Word for Windows โดยจัดระยะขอบบน 3.0 ซม. ระยะขอบขวา ขอบซ้ายและขอบล่าง 2.5 ซม. โดยมีการตั้งค่าขนาดของกระดาษ Custom size (19 ซม.x26.5 ซม.) หลัง "***คำสำคัญ:***" ให้กำหนดรูปแบบเป็น 2 สดมภ์ ด้วยความกว้าง 6.73 ซม. และระยะห่างสดมภ์ 0.5 ซม. พิมพ์บทความด้วยอักษร Angsana New ขนาด 13pt ความยาวของบทความไม่ควรเกิน 15 หน้า และสำหรับคำ ***บทคัดย่อ คำสำคัญ*** และ***เอกสารอ้างอิง*** ให้กำหนดเป็นตัวเข้ม-เอียงด้วยอักษร Angsana New ขนาด 14pt

คำสำคัญ **:** เว้น 1 บรรทัดหลังจากบทคัดย่อ แล้วพิมพ์คำสำคัญของบทความ (4-5 คำ)

Abstract This is a template of your full paper for publishing on SAU JOURNAL OF SCIENCE & TECHNOLOGY. Use Microsoft Word for Windows. Leave 3.0 cm. margins from the top, 2.5 cm. from the right side, left side and bottom. Please adjust the page setup to custom size (19 cm.x26.5 cm.) sheet. Use double-column format width of 6.73 cm. with a space of 0.5 cm. between columns after the keywords. Use 11 point Times New Roman font in typing the abstract. The length of paper should not be longer than 15 pages. For the headings, such as ***Abstract***, ***Keywords*** and ***References*** use 12 point Times New Roman bold-Italic.

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1. บทนำ

ชื่อบทความภาษาไทย (ใช้ตัวอักษรAngsana New ขนาด 20pt ตัวเข้ม กลางหน้ากระดาษ) ตามด้วยชื่อบทความภาษาอังกฤษ (ใช้ตัวอักษร Times New Roman ขนาด 16pt ตัวเข้ม กลางหน้ากระดาษ) จากนั้นเว้น 1 บรรทัด ตามด้วยชื่อผู้ประพันธ์ (ใช้ตัวอักษรAngsana New ขนาด 13pt ตัวเข้มกลางหน้ากระดาษ) ภาค/สาขาวิชา สถาบัน/มหาวิทยาลัย (ใช้ตัวอักษรAngsana New ขนาด 13pt กลางหน้า) และที่อยู่/ประเทศ(ใช้ตัวอักษรAngsana New ขนาด 13pt กลางหน้า) จากนั้นระบุ email address ของผู้นิพนธ์ประสานงาน (ใช้ตัวอักษรTimes New Roman ขนาด10pt กลางหน้า) หัวข้อเรื่องแต่ละข้อ (ใช้ตัวอักษร Angsana New ขนาด15pt หนาชิดขอบซ้าย) โดยใช้หมายเลขแบบฮินดู อารบิก (1, 2, 3,…) ไม่ใช้แบบเลขโรมัน (I, II, III, …).

2. วัสดุ อุปกรณ์และวิธีการวิจัย

สรุปอธิบายถึงขั้นตอนการทดลองและการวิเคราะห์และมีข้อมูลที่เพียงพอสำหรับคนอื่นๆ ที่จะสามารถที่จะทำให้เกิดการทดลองซ้ำได้

3. ผลการทดลองและอภิปรายผล

สำหรับชื่อหัวข้อใหญ่ใช้ตัวอักษรAngsana New ขนาด 15pt, ตัวเข้ม ชิดขอบซ้าย เรียงลำดับหัวข้อด้วย 1, 2, 3,.... (ไม่ใช่ I, II, III,…) การขึ้นหัวข้อใหม่แต่ละครั้งให้เว้น 1 บรรทัด สำหรับสมการคณิตศาสตร์ให้จัดเรียงด้วย (1), (2), (3),...

3.1 หัวข้อย่อยลำดับที่ 1

หัวชื่อข้อย่อยลำดับที่ 1 ใช้ตัวอักษร Angsana New ขนาด 13pt ตัวเข้ม ชิดขอบซ้าย

3.1.1 หัวข้อย่อยลำดับที่ 2

หัวชื่อข้อย่อยลำดับที่ 2 ใช้ตัวอักษร Angsana New ขนาด 13pt ตัวเข้ม ชิดขอบซ้าย

3.2 ตาราง รูป และการอ้างอิง

สำหรับรูปภาพตารางและการอ้างอิงตัวเลขควรเป็นเลขดังนี้ รูปที่ 1 รูปที่ 2, ... ฯลฯ (ที่กึ่งกลาง) และตารางควรจะเป็นเลขดังนี้ Table1, Table2 …ฯลฯ (ที่ด้านซ้าย) การอ้างอิงในบทความให้ใช้เครื่องหมายวงเล็บเหลี่ยม เช่น [2] จะต้องเรียงลำดับหมายเลขอ้างอิงจากหมายเลขน้อยไปสู่หมายเลขมากให้ถูกต้อง การอ้างอิงหมายเลขที่มีลำดับติดต่อกัน ตัวอย่างเช่น[1-5]

4. สรุปผล

เพื่อให้ทุกบทความที่ได้รับการพิจารณาตีพิมพ์มีรูปแบบที่ตรงกัน ผู้ประพันธ์จะต้องจัดทำบทความตามต้นแบบ ไม่เช่นนั้นบทความของท่านจะถูกส่งคืนเพื่อปรับปรุงรูปแบบให้ตรงกับต้นแบบนี้ขอขอบคุณท่านสำหรับการให้ความร่วมมือ

5. กิตติกรรมประกาศ

ในส่วนนี้ไม่จำเป็นต้องมี แต่ท่านสามารถใช้ส่วนนี้ในการนำเสนอให้ทราบถึงผู้ที่สนับสนุนการทำงานวิจัยของท่าน เช่น นักศึกษาที่มีส่วนร่วม ผู้ที่มีส่วนร่วมจากภายในหรือภายนอก หรือองค์กรที่ให้ทุนสนับสนุน

6. หลักเกณฑ์ในการเขียนเอกสารอ้างอิง

การเขียนเอกสารอ้างอิงกำหนดให้ใช้ ตัวอักษร Angsana New ขนาด 13pt และเขียนตามตัวอย่างของเอกสารอ้างอิงในแม่แบบนี้ กรณีที่เป็น

เอกสารอ้างอิง [1] หมายถึง “หนังสือ”
เอกสารอ้างอิง [2] หมายถึง “รายงาน”
เอกสารอ้างอิง [3] หมายถึง “วารสาร”
เอกสารอ้างอิง [4] หมายถึง “ประชุมวิชาการ”

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เอกสารอ้างอิง

[1] M. Ned, U. M. Tore and R. P. William, Power Electronic, John Wiley and sons, 1995.

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