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Battery Thermal Management System

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BATTERY THERMAL MANAGEMENT SYSTEM

Synopsis Report

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Declaration

I/we declare that this written submission represents my/our ideas in my/our own words and where others ideas or words have been included; I/we have adequately cited and referenced the original sources. I/we also declare that I/we have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my/our submission. I/we understand that any violation of the above will because for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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ABSTRACT

The increasingly environment pollution and energy shortage problem has led to look for clean energy and energy saving technologies to be used in the transportation field. Electric Vehicles are one of such technology that can reduce the pollution significantly. The project is designed to overcome the problems that current electric vehicles face due to inefficient battery thermal management system (BTMS). The performance of lithium batteries used in electric vehicles predominantly depends upon the operating temperature. When this temperature exceeds the safety level then thermal runaway occurs in batteries and performance drops. The challenges involve in this task includes a design that is effective in heat transfer, light in weight and compact.

The Lithium-ion battery have a narrow operating temperature range of between 15 and 50°C.The functional safety, service life, and cycle stability of the battery cell and the entire electric car depend to a large extent on the battery cell remaining in this range. The project develops a thermal management system using mini channel aluminum plates with silicone pads. The high conductivity of aluminum plates is exploited to effectively drain heat from the battery. The thermal contact area is increased using silicone pads. Ethylene glycol water solution flowing through the mini channels extracts the heat from the aluminum plates.

Several battery thermal management methods have been introduced to avoid over-heating thermal runaway which includes air cooling, liquid cooling, phase change materials and heat pipe cooling. Heat generation rate of battery is an important parameter that is considered in design of any BTMS. Researchers have shown that the heat generation rate of the tested battery increases with the discharge rate and decreases with the operating temperature. Experiments have proved that pressure drop of coolant decreases with increase of the cross-section and number of the coolant channels making the cooling system efficient.

CONTENTS

Chapter 1: Overview

1.INTRODUCTION

Industrialization and globalisation have increased the demand of energy considerably. Energy consumption pattern has indicated that the world energy consumption will increase by 50% before 2030. Majority of the demand of energy in current world is met by fossils such as oil, natural gas, and coal. Degradation of environment occurs from the large-scale consumption of these energy sources. The prices of these sources have increased considerably over the past decade. These reasons have led researchers to look for more efficient and eco-friendly energy sources. Transportation is a major sector in which large scale consumption of these sources occur and several alternatives to conventional vehicles have been developed to overcome the problem. Electric and hybrid electric vehicles are the two leading alternatives.

An electric vehicle (EV) operates on electric motor instead of an internal combustion engine that produces power by combustion of fuel and gases. Hybrid electric vehicles (HEV) on the other hand are powered by both combustion engine and an electric motor. The electric motor EVs and HEVs is powered by batteries. Lithium-ion batteries are generally used in these vehicles due to their high power to weight ratio and high energy efficiency. The performance of Lithium-ion battery cells is greatly affected by their operating temperature. These batteries suffer from Goldilocks effect; they do not perform efficiently when operating temperature is too hot or too cold. Optimum operating range of Lithium battery is between 20°C and 45° C. When this temperature exceeds the safety level then thermal runaway occurs in batteries.

Thermal runaway of the lithium-ion battery initiates an unstoppable chain reaction. The temperature rises rapidly within milliseconds and the energy stored in the battery is suddenly releases. Temperatures of around 400° C are reached, battery becomes, and a fire erupts that can hardly be extinguished by conventional means. The risk of thermal runaway begins at a temperature of 60° C and becomes extremely critical at 100° C. Thus, a battery thermal management system (BTMS) becomes essential to increase the lifetime of cells by regulating the temperature level of the battery.

Liquid, air, phase change material (PCM) and heat pipe are the cooling methods that are generally employed in a BTMS. Liquid cooling is the most effective cooling method but suffers from leakage potential. Air cooling is simple, low cost and high maintainability cooling method but it leads to non-uniform temperature distribution within the battery cell because of its low capacity. The phase change materials have high latent heat and acts as a heat sink during discharge. When the cells are on standby, the PCM releases heat to the cells and the environment. This way the cell temperature will stay at the right temperature for long time. However, they suffer from problem of not changing phase within the required temperature range of the application, large volume expansion and high cost. Despite of the significant developments an urgent need remains for developing safe, high-efficient, and cost-effective thermal management systems.

2.SCOPE OF THE PROJECT

In the face of life-threatening safety issues, innovation is continuously happened in electric vehicle industry to improvise the battery cooling system. Methods such as air cooling, fan cooling, liquid cooling such as using PCM, plate and heat pipes are usually employed in current vehicles. Nissan leaf electric vehicle models uses air cooling for the battery pack. The company has not implemented any kind of liquid cooling or any other method. Air cooling is unsuitable for most high-performance application due to power density required by the system and the inability to cope with a large fluctuating ambient temperature. It is not possible to remove the heat from the battery with an air system cooling alone, some air cooling will definitely occur on the battery which is positioned on the underside of the vehicle due to the air flow during driving but this is insufficient to meet the full cooling needs of the battery. Hence chances of thermal runaway are high in air cooling.

BMW electrics vehicle uses the direct refrigerant type of cooling in their vehicle to maintain their battery pack at an optimum temperature level. They use base plate which incorporates liquid cooling with the presence of water and glycol as a refrigerant. The refrigerant comes from the existing A/C of the vehicle. The battery pack has a bottom cooling plate with refrigerant flowing through it. The design is simple but heavier in construction. It also uses the tab cooling which is mounted on the top which helps in the directional cooling of the cell but also results in improper cooling of the cell which can give rise to hotspots in the cell. These hotspots on the cells may damage the cells.

Audi uses the directional cooling because of the orientation of the battery pack. They use 4 heat exchangers which are interleaved within the battery pack, but the heat exchangers appear to be deliberately positioned at the base end of the cells from the tabs. This increases the complexity of the system. Also, tab cooling is difficult due to the need to electrically isolate the cooling system to prevent short circuit of the pack and also to ensure that no failure of the cooling at joints results into the battery pack itself.

Research and scientific evaluations are continuously going on to overcome the above-mentioned problems. The basic need of making the battery compact and lightweight makes the technological advancement in this domain a difficult task. This project tackles these problems by modifying the cooling plate setup with a mini channel design and using cooling pads. For space reduction, a cooling plate is sandwiched two cells which provides the required surface cooling to the cell. In addition to that the placements of cell are in such a way that they also get cooled by the air flowing from the bottom of the car. The weight of the system is decreased by selecting aluminium as the cooling plate material. The high thermal conductivity aluminium plates are exploited to effectively drain heat from the battery. The thermal contact area is further increased using silicone pads. Ethylene glycol water solution flowing through the mini channels extracts the heat from the aluminium plates. This design avoids the thermal runaway problem in vehicles

3.PROBLEM DEFINITION

Lithium iron phosphate batteries have a potential safety concern when it comes to temperature. Lithium-ion batteries have a narrow operating temperature range and the functional safety, service life, and cycle stability of the battery cell and the entire EV or HEV depend to a large extent on the battery cell remaining in the optimum range. If the temperature exceeds a critical level, thermal runaway occurs. Thermal runaway leads to chances of fire break out in vehicles. A thermal management system is therefore essential.

4.OBJECTIVES

- To protect the cells of a battery from damage in abuse/failure cases
- To protect the operator of the host application.
- Maximize the performance which includes power and energy delivered by the battery
- To limit the absolute temperature of battery cells below the limiting value.
- To make the temperature distribution uniform between the battery cells.
- To protect the Battery and prolongs the service life of the battery pack.

Chapter 2

Literature Survey

Kaiwei Chen [1] developed a method of heat generation measurement for a prismatic battery which is applicable to any prismatic battery regardless of chemistries. An experimental facility is developed to study the effects of battery operating temperature on discharge characteristics. A constant temperature thermal bath is created, and 50-50 water-ethylene glycol solution is employed for battery temperature control. Heat generation rate of a 20Ah prismatic A123 LiFePO4 battery is measured under a wide range of discharge rates and operating temperature with discharge ranging between 0.25C and 3C and operating temperature ranging between -10˚C and 40 ˚C. It is shown that the heat generation rate of the tested battery increases with the discharge rate and decreases with the operating temperature.

Ben Ye et.al [2] developed a methodology for the design and optimization of the cooling plate for the battery module. The battery module consisted of 15 cells having nominal voltage 3.2V making the battery module voltage as 48 V. A complex heat transfer model for the whole module was created including batteries cooling plates and coolant. In the analysis, cooling plates were placed above and below the combination of cells and 50-50 ethylene glycol and water is used as coolant. Orthogonal experimental design is implemented to optimize the main parameters of module. The parameters under consideration were Battery gap, cross section size and the number of coolant channels of the cooling plate. In the design optimization, the number of cooling channels were iterated, the inlet charge rate was also changed and the results showed that the pressure drop decreased with the increase of the cross-section and number of the coolant channel when the coolant flow rate is constant at the inlet.

Abdul Haq Mohammed et. al [3] developed a cooling plate which featured pins with staggered arrangement inside the cooling plate to extend the effective heat transfer area between the cooling plate and the coolant with minimum coolant pressure-drop in the cooling plate . The performance of battery was examined for aggressive discharging during the normal operation and thermal runaway of fully discharged battery. Two different designs of the cooling plate was constructed and simulation results showed that both cooling plates were capable of maintaining battery temperature but it was observed that coolant pressure-drop for one of the design was much lower than the other design. Hence, the pressure-drop became the deciding factor for the selection of the cooling plate.

Jian Xu et. al [4] carried out the simulation of mini-channel cooling plate on the nail penetration. Three of the five cells were wrapped by square aluminum shape mini channels. Nail penetration was used to release the energy, which results in temperature increase. The process consisted of two mechanism i.e. the short circuit and the thermal abuse. The simulation showed that increasing the flow rate will not prevent the thermal runaway and nail penetration depth will cause a more severe and faster thermal runaway. It was concluded that at the battery module level, a mini-channel cooling system with independent control of the coolant flow rate for individual cells can prevent the propagation of thermal run-away from one cell to its neighboring cells.

Wang C, Zhang G, Meng L, et al [5] performed experiments and simulations related to cooling capacity provided by cooling plates to the batteries. The material used for cooling plates was thermal silica and copper tubes were passed through it for flow water as coolant. Simulations were performed based on various factors which included the effect of charge density, number of channels, direction of flow and the velocity of the flow. The experiment showcased the non-linear relationship of the temperature of the battery to the number of cooling plates and liquid channels. Iterations were also performed to establish a relationship between the capacity rates of battery with the inlet flow rate, for example, a 5C discharge rate battery required an inlet flow rate of the simulations showed that liquid cooling was more efficient along with PCM than air cooling 0.25m/s. It was also verified that the direction of coolant flow had no appreciable effect on the temperature, but the rate at which the coolant entered the channel had an appreciable effect on the performance.

CHAPTER 3

DESIGN AND ANALYSIS

I. HEAT GENERATION IN BATTERY CELL

Heat generation in a battery cell can be attributed to two main sources [6]: (1) entropy changes due to electrochemical reactions and 2) ohmic heating. Depending on the electrode pair, reaction heat can be endothermic for charging and exothermic for discharge. Ohmic heating is due to the transfer of current across internal resistances.

The heat generation rate in a cell can be calculated from:

$$\boldsymbol{Q = I(V_{OC} - V) - I\left[T\left(\frac{dV_{OC}}{dT}\right)\right]} \qquad (1)$$

The second term in Equation (1), $I\left[T\left(\frac{dV_{OC}}{dT}\right)\right]$ is the heat generated or consumed because of the reversible entropy change resulting from electrochemical reactions within the cell. The first term, $I(V_{OC} - V)$ is the heat generated by ohmic and other irreversible effects in the cell. With practical EV and HEV, the second term is generally negligible compared to the first term.

It is difficult to accurately characterize the heat generation rate of batteries due to the complexity of vehicle operating conditions. Calorimetric experiments are generally done to obtain the heat generation rates at all tested discharge rates and battery operating temperatures. Table 1 indicates heat generation rate for different discharge rates of a 20 Ah $LiFePO_4$ prismatic battery.

Table 1[2].

Battery Temperature(˚C)	Discharge Rate-Watts(W)				
	0.25C	0.5C	1C	2C	3C
10	1.43	4.37	8.87	16.72	24.79
20	0.87	3.32	4.9	13.7	20.41
30	0.85	1.86	4.56	10.39	16.48
40	0.71	1.62	3.7	7.88	14.21

II. DESIGN OF CELL

Li-ion battery, LiFePO4, with a nominal capacity of 20Ah is selected. It is assumed that the heat generated inside the cell and thermophysical properties are uniform. The energy conservation of the cell is described by the following equation:

$$\rho C_P \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right) + q$$

where ρ is the average density and C_P and k present the specific heat and thermal conductivity of the battery, respectively. The heat generation rate is represented by q. The parameters of the cell used is listed in the table 2.

TABLE 2[3].

Property	Parameter
Cell Type	Prismatic
Capacity	20 Ah
Nominal Voltage	3.2 V
Discharge Cut Off Voltage	2.3 V
Specific Heat	733 $J.kg^{-1}k^{-1}$
Conductivity	2.7 $W.m^{-1}.k^{-1}$
Density	1958.7 $kg.m^{-3}$
Height	140mm
Width	100mm
Thickness	20mm

III. Design of Cooling Plates

The material selected for the cooling plate is aluminum 6061 because of its lightweight, high strength to weight ratio and high thermal conductivity. The dimensions of aluminum plate are 5mm*100mm*140mm.Circular holes are extruded in aluminum plate having diameter 3mm.Each plate has 28 such holes

.The mini channels increase the flow rate of coolant and at the same time provide minimum pressure drop leading to reduced pumping power. Silicone pads of 1.5mm thickness are placed between the cell outer surface and aluminum plates to reduce thermal contact resistance. Silicone pads work as perfect gap filler and bridges the uneven surface because of its low hardness and great compressibility. The complete system design is shown in figure 1 and figure 2 represents the enlarged image of plate. The properties of aluminum plate and silicone pads are given table 3.

TABLE 3

Parameter	Units	Aluminium 6061	Silicone
Density	kg.m^{-3}	2700	3050
Specific Heat	J.kg^{-1}k^{-1}	900	0.832
Conductivity	W.m^{-1}k^{-1}	201	6
Height	mm	140	140
Width	mm	100	100
Thickness	mm	5	1.5

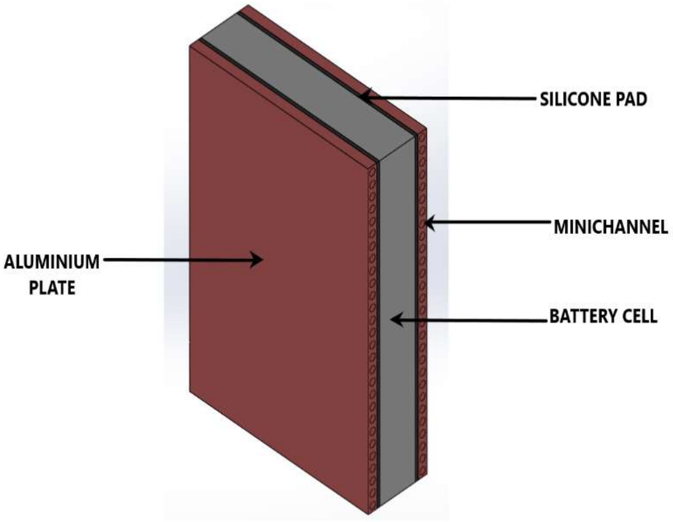

Figure 1 COOLING SYTEM DESIGN

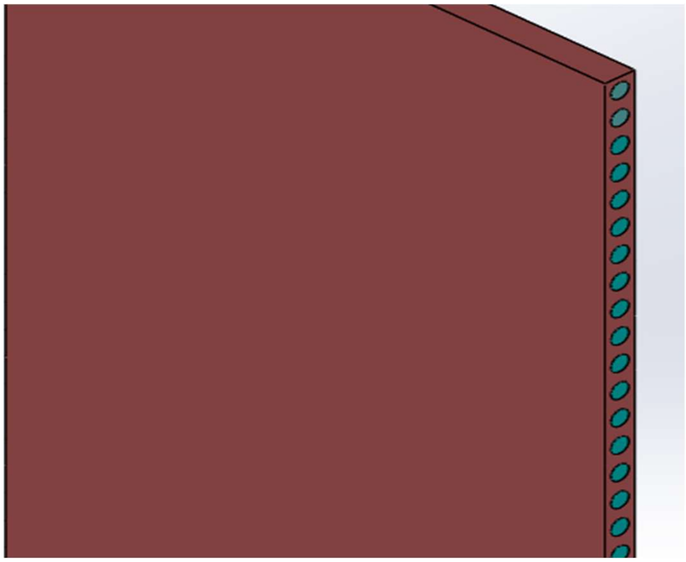

Figure 2 ENLARGED VIEW OF ALUMINIUM PLATE

IV.SELECTION OF COOLANT

Water is the most efficient heat transfer fluid known till now. The problem with the water is that it has poor anti-freeze and anti-evaporative properties. The use of glycol along with water overcomes the above drawbacks. The glycol water solution last 12 years or longer provided corrosion inhibitor strength is maintained.

Ethylene glycol is used due to several reasons

1. To provide freeze protection and burst protection.
2. To provide anti-corrosive properties to the water.
3. Increases the heat capacity of water when required.

Higher flowrates lead to higher pressure drops, energy consumption, and equipment wear. As a result, it is important to accurately determine the minimal concentration of glycol needed to do the job to maintain system efficiency. Ethylene glycol has lower heat-transfer efficiency than water and is denser, resulting in higher volumetric flowrates. Higher flowrates lead to higher pressure drops, energy consumption, and equipment wear. Hence an optimum solution of ethylene glycol and water is chosen to maintain cooling system efficiency. In this design analysis, we have used 50-50 ratio of ethylene glycol and water for optimum properties. The properties of the above ratio are mentioned in Table 4.

Table 4[8]

Parameter	Units	50-50% Ethylene glycol water solution
Density	$kg.m^{-3}$	1092
Specific Heat	$J.kg^{-1}k^{-1}$	3200
Conductivity	$W.m^{-1}.k^{-1}$	0.405
Kinematic Viscosity	m^2s	9×10^{-6}

CHAPTER 4: PLANNING

GRANTT CHART

Sr. No.	Action Plan	Duration (Months)	2020							2021			
			Jun-20	Jul-20	Aug-20	Sep-20	Oct-20	Nov-20	Dec-20	Jan-21	Feb-21	Mar-21	Apr-21
1	Idea formulation	1	🟩										
2	Literature Review	5	🟩	🟩	🟩	🟩	🟩						
3	Checking feasibility of Project	2		🟩	🟩								
4	Finalizing Research Methodology	4	🟩	🟩	🟩	🟩							
5	Deciding Domains/Dividing indiviual goals	3	🟩	🟩	🟩								
6	Designing and Testing	5			🟩	🟩	🟩	🟩	🟥				
7	Conducting tests and other simulations	6				🟩	🟩	🟩	🟩	🟥	🟥		
8	Start of production	2								🟥	🟥		
9	Prototyping	3							🟥	🟥	🟥		
10	Final product	11	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥

CONCLUSION

In this paper, challenges, prospectus, and importance of thermal management in EVs and HEVs are mentioned. Based on the new design and simulation we can expect several conclusions as mentioned below:

1. Due to new design, reduction in the overall battery size and its weight is achieved. Reduction in the manufacturing as well as the running cost of the battery.

2. Due to the compact design and the placements of the cells, the space is increased. Packaging efficiency of module is increased as we have made sandwich type layer structured of battery and cooling plates.

3. The liquid cooling system is more effective in extracting the heat generated from the prismatic cell and maintaining the optimum environment for the battery.

4. The problem of the unbalanced cells can be reduced, and the cycle life of cell can be prolonged, and the safety of application user is increased.

5.As we have used Silica pad in our model, it acts as a perfect gap filler between the aluminum plates and the battery to reduce the thermal contact resistance.

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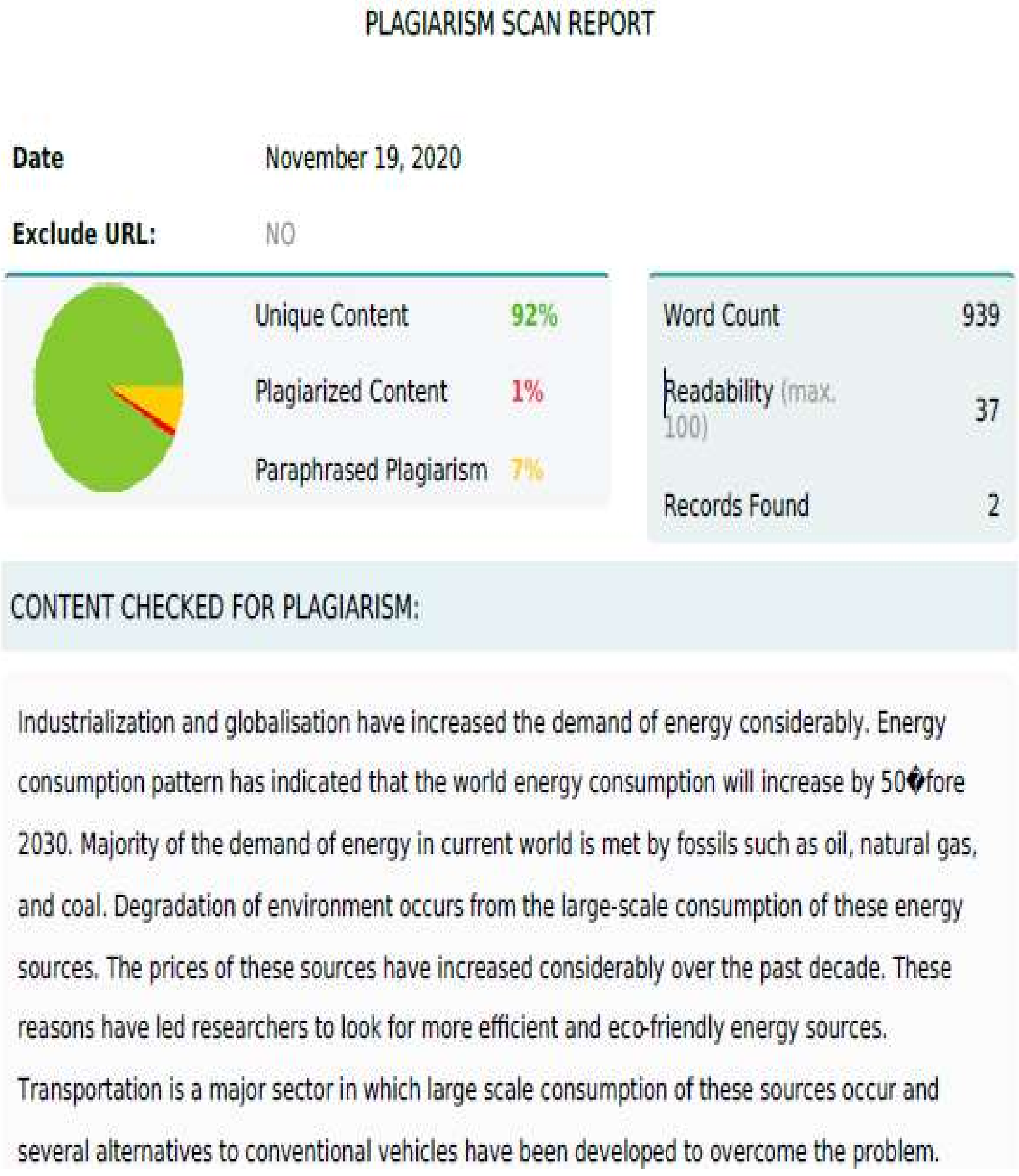

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Industrialization and globalisation have increased the demand of energy considerably. Energy consumption pattern has indicated that the world energy consumption will increase by 50�fore 2030. Majority of the demand of energy in current world is met by fossils such as oil, natural gas, and coal. Degradation of environment occurs from the large-scale consumption of these energy sources. The prices of these sources have increased considerably over the past decade. These reasons have led researchers to look for more efficient and eco-friendly energy sources. Transportation is a major sector in which large scale consumption of these sources occur and several alternatives to conventional vehicles have been developed to overcome the problem.