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NEW GENERATION FABRIC BASED ELECTRICAL HEATING SYSTEMS: A CASE STUDY FOR PUBLIC TRANSPORT VEHICLES

[1]HAYRI EREN, [2]VOLKAN KIRMACI, [3]MUSTAFA EROL, [4]AHMET YAVAS, [5]HUSEYIN DURAN, [6]YAVUZ OZTURK

[1,6]Anadolu Isuzu Otomotiv San. and Tic. AS, Kocaeli,Turkey
[2]Bartin University Mechanical Engineering Department, Bartin, Turkey
[3,4]Izmir KatipCelebi University, Engineering and Architecture Faculty, Materials Science and Engineering Dept., Izmir, Turkey
[1,5]Bartin University, Science Institute, Mechanical Engineering Department, Bartin, Turkey
E-mail: [1]hayri.eren@isuzu.com.tr, [2]volkankirmaci@bartin.edu.tr, [3]mustafa.erol@ikc.edu.tr, [4]ahmet.yavas@ikc.edu.tr, [5]huseyindurann@yandex.com, [6]yavuz.ozturk@isuzu.com.tr

Abstract - Internal Combustion Engine vehicles use engine waste heat as a heat source to heat up the passenger compartment and to provide comfortable and safe environment inside the vehicle. When there is no Internal Combustion Engine and hence no such waste heat or when the waste heat from Internal Combustion Engine is not enough to warm up passenger compartment, the necessary heating has to be provided by an alternative energy sources. Supplementary fuel burner heaters or battery powered electrical heaters are the only available heating units that can be used to supply such amount of heat power. As a result of low zero emission expectation and low fuel consumption expectation, there are many studies done specifically based on electrical heating, however most of them consumes energy in an inefficient way and therefore less preferred. In this paper, a theory of an alternative and novel heating method for transport vehicles is studied. Study targets to reduce energy consumption as well as weight of heating system. Suggested system is aimed to heat up the occupants directly using an infrared heating technology from fabric based infrared heating elements so that overall efficiency of the system will be increased and energy consumption is expected to be reduced.

Index terms - Infrared Heating, Fabric Heating, Public Transport Vehicle Heating, Innovative Heating

I. INTRODUCTION

A basic heating circuit for a coach with an Internal Combustion (IC) Engine can be seen on Figure 1. Main system components are; engine coolant, circulation pump, fuel burner heaters, motorized valves, distribution box, piping, convector heat exchangers and blower heat exchangers. System uses the waste heat from IC engine and heats up cabin air and occupants using coolant-air heat exchangers which are located on both sides of the passenger compartment.

In order to reach adequate warming and a certain level of comfort inside the cabin, engine coolant which carries the IC engine waste heat to the heat exchangers need to be warmed up initially. Depending on whether fuel burner heater (add on heater) is used or not, this process may take time from20 minutes up to around an hour or so (Figure 2).Cabin warm-up period is also highly effected by overall system efficiency, heat distribution inside the cabin [2] as well as engine load during warm-up period [1,7]. In some cases, fuel burner heaters as mentioned above, are used as an additional heat source when engine is running or before the start-up in order to shorten the initial warm-up period (Figure3). To sum-up, passengers thermal comfort is highly depended on whether the IC engine provide an adequate heat or not. And to maintain passengers comfort sometimes even more energy, which means more fuel, is required.

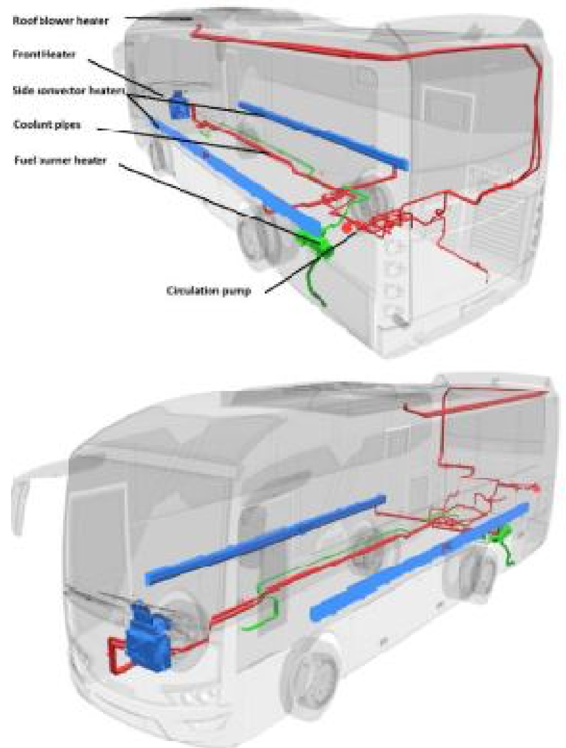

Figure 1: An IC engine coach heating system

As mentioned above, additional fuel burner heaters or alternative energy source heaters may help to keep thermal comfort inside the passenger compartment when there is no IC engine like in electric vehicles or when IC engine waste heat is not enough as like in warm-up period. However, because of overall system’s low efficiency add on heaters fuel consumption is dramatically high (for a coach size vehicle) and hence less preferred. In addition to that, fuel burner heaters will also increase emissions which becomes more important every other day.

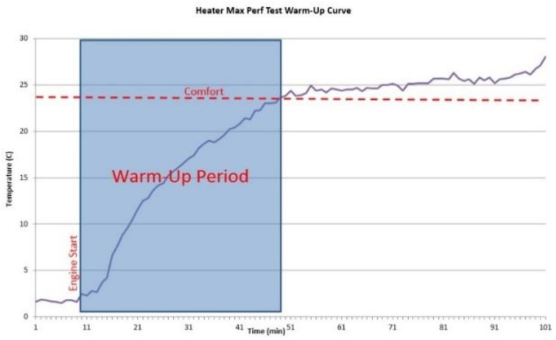

Figure 2: An IC engine coach Warm-Up curve.

Other than fuel burner heaters, there are also some other heating solutions which has still being studied like heat pumps, PTC air heaters and PTC coolant heaters [3,4]. However, all of the above mentioned heating systems use almost same heating strategy with the conventional IC engine cabin heating system. They all uses indirect heating strategy, which is focused on heating the cabin air by heat exchanger and expecting to warm-up occupants to their comfort level by using heated cabin air. Therefore their expected efficiency stays low and energy consumption is considerably high [4].

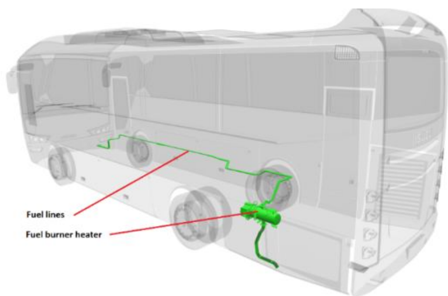

Figure 3: Additional Fuel Burner Heater.

Because infrared (IR) heating provides a direct heating of components it may provide a considerable difference compared to above mentioned conventional heating systems in vehicles. Direct heating may also provide considerable energy saving as well as quick response and better comfort compared to available systems [5]. There are very few studies available in the literature which are done for vehicle infrared heating, however they mostly based on rigid infrared heating panels which are heavier and not suitable to use as an interior component in a passenger vehicle [4, 6].

This article is based on a theory of a novel fabric based infrared (IR) heating element to be used as an interior coating material of a coach (Figure 4). Because textile heating element will be extremely light and flexible compared to conventional heat exchanger systems, a major weight reduction as well as energy saving is expected. In literature there are some reports dealing with fabric based heating elements. For example; Christian I. *et al.* promoted a heating element which is designed to adapt in to woven flexible structures. Additional metallic yarns, used as electrodes, are integrated in a woven structure (or sewn into textile) in a comb-teeth arrangement. They employed carbon black powders in a polymer matrix which is embedded in to a fabric to obtain intended conductivity and heating functionality [8]. In another study, Hamdani et al. reported a textile heating fabric based on silver and polymeric yarn heating element [9]. In the article of Wang *et al.* it is reported that carbon-based coatings were applied on glass fiber fabrics and investigated their performance for various application voltages [10]. As understood from above reported studies about fabric based heating, it can be declared that our study stands one step ahead when the materials with heating functionality, heating element design and their applications are considered especially for vehicles. It can also be expressed that, to the best of our knowledge a system with same manner of approach has not been reported yet.

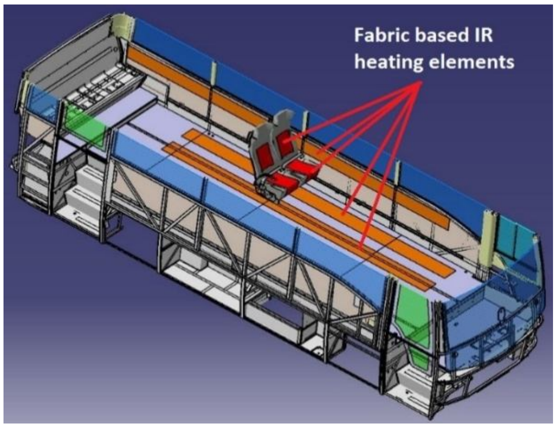

Figure 4:Fabric based infrared (IR) heating elements inside the cabin

II. EXPERIMENTAL STUDY

Fabric based heating elements consist of several components: modified polyester yarns, modified carbon fibers and silver plated wires as fabric matrix, functioning element (resistance) and electrical input terminal respectively. A schematic illustration of design and a sectional image of the final product with components are given in Figure 5. Regarding to below mentioned design, a classical weaving procedure was applied, and where carbon fibres and polyester yarns aligned in horizontal direction while silver plated wires were vertical so as to form a typical parallel resistance circuit. All the components used in design and manufacturing of the fabric based heating elements are used as produced without further purification or processing.

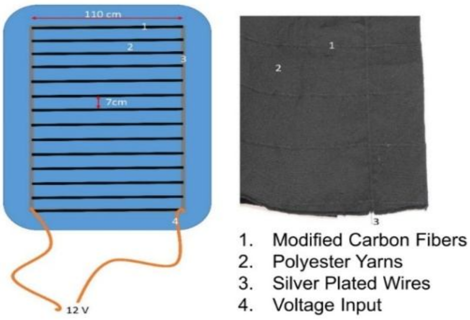

Figure 5: Woven fabric based heating element: design (left) and a section of final product (right).

Design depicted in Figure 5, was applied to produce heat since weaving operation is an appropriate processing method for scale up and mass productions of fabrics. Subsequent to design and production issues, electrical and heat releasing behaviours of samples were evaluated. Input potential decided as 12 volts, based on vehicle battery voltage. As it can be seen from design; heating elements can be considered as parallel resistance circuit with fourteen equal resistances (carbon fibers) in parallel. With this manner, electrical measurements of carbon fibers were performed using a multimeter in order to determine relationship between length and resistance of carbon fibers. Sequentially, a 20 cm intersection of a carbon fiber is taken and its heat release was determined via thermal camera with regarding voltage. Finally for the product with dimensions as shown in Figure 5, was subjected to 12 V input and its performance was detected using a thermal camera.

III. RESULTS AND DISCUSSION

Relation of resistance between lengths of carbon fiber is an important point for a fabric based heating element. Resistances of carbon fibers with varying lengths from 0-100cm were measured and shown in Figure 6. Regarding to this figure it can be directly expressed that there is a linear proportional relation between length and resistance of fibres. Linear relation can be fitted as $y=0.3899x$, $R^2=0.9971$; where x, y and R denotes length, resistance and mean square error.

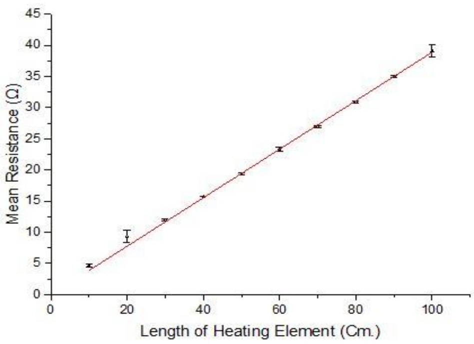

Figure 6: Relation between resistance and Length of Heating Element

The input voltage for whole element is considered as 12 V, so it can be addressed that the regarding voltage for a 20 cm section will be proportionally 2.4 V. By applying 2.4 V to this section, released heat for 30 minutes were recorded for several intervals and depicted in Figure 7.

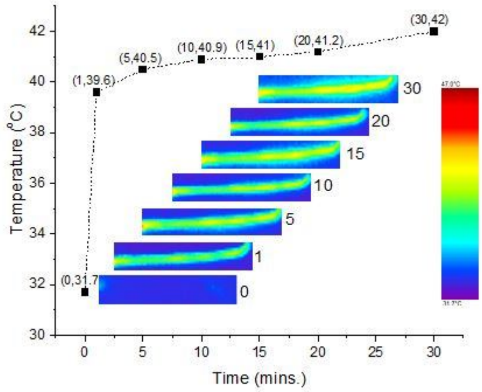

Figure 7: Hating performance of a 20 cm fibre section.

Based on to this experiment it can be declared that, temperature immediately increases to 40^{0}C in one minute and then slightly continues to increase up to 42 ^{0}C. In order to demonstrate performance of a whole heating element, thermal imaging is also performed as illustrated in Figure 8. Both thermal measurements show that active warmer surfaces can be evaluated as heating elements in vehicles, in accordance with application places, heat requirements and conditions.

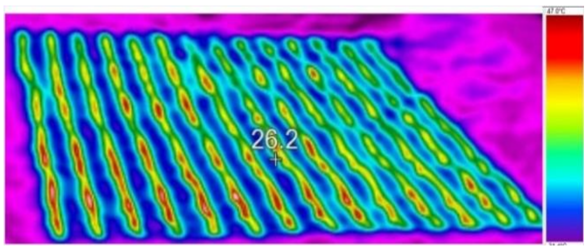

Figure 8: Heating performance of the whole heating element.

CONCLUSION

In this study, a novel fabric based heating element is designed and produced successfully based on design for both sectional and whole element surface temperatures up to 42 ^{0}C were obtained. It can be inferred that results are promising but a detailed design and manufacturing operations should be performed for future applications regarding to critical points in the vehicle where heating requirements may vary.

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