

Development of Tank Shell and Tube Material for Plastic Fuel Tank to Comply with PZEV

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ABSTRACT

A plastic fuel tank system compliant with U.S. PZEV evaporative emission standards was developed and fitted on the new CIVIC-IMA. Techniques for reducing the high permeation that occurs from the tank shell and various tank system components, such as plastic tubes, pump gaskets, and other welded child parts, were studied.

EVOH with 24 mol% ethylene content was chosen for the low-permeation layer of the plastic fuel tank shell, and the fuel permeation rate was reduced to one-fifth that of the conventional tank shell.

Modified PPS was chosen for the low-permeation tubing material. The modified PPS was alloyed with an elastomer to produce a tube with the required flexibility. By using this material, the rate of fuel permeation of the tube alone could be reduced to one-tenth that of conventional tubes.

Additionally, compared to the regulatory value of 54 mg/day for the fuel tank system, a permeation rate of less than 54 mg/day was achieved during measurement using Phase III fuel after adding low permeation parts such as pump gaskets and welded child parts.

1. Introduction

U.S. PZEV evaporative emission standards, which came into force in 2004, are currently the most stringent in the world. These regulations require the fuel permeation rate from all parts of the fuel system to be below 54 mg/day, using Phase II fuel, including methyl tertiary butyl ether (MTBE), as the test solution⁽¹⁾.

However, gasoline additives in the U.S. market have been changing over from MTBE to ethanol, while test solutions have also been changing over to Phase III fuel, including ethanol. The swelling of plastic and rubber materials in ethanol is high compared to MTBE, and the rate of fuel permeation is also higher in ethanol. Thus, the test becomes more stringent in the case of Phase III fuels⁽²⁾.

In view of this background, steel tanks began to be used to clear PZEV emission standards.

Since plastic fuel tanks possess a high degree of freedom in shape and are lighter compared to steel tanks, more than 90% of all Honda vehicles are fitted with plastic fuel tanks. However, since fuel permeation from plastic fuel tanks is greater than it is from steel fuel tanks, technology allowing for compliance with PZEV standards was nonexistent. Therefore, a plastic fuel tank system that could comply with PZEV standards was in demand.

A plastic fuel tank system complying with PZEV evaporative emission standards has been developed, and its development is introduced in this report. The newly developed tank system has been fitted on the new CIVIC-IMA. Figure 1 shows the plastic

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fuel tank system on the new CIVIC-IMA and the parts that incorporate elemental technology for reducing fuel permeation. This completely built car fitted with a plastic fuel tank complies with PZEV standards in SHED tests using Phase III fuel. By using a fuel tank made of plastic, a weight reduction of about 3 kg was achieved, compared with the use of conventional steel fuel tanks.

2. Elemental Technology for Reducing Fuel Permeation

Figure 2 shows the measured results of fuel permeation from the plastic fuel tank system. Phase III fuel was used for the SHED method to measure the permeation. To examine its contribution to permeation, each component was closed by a blank plug, ensuring that no permeation occurred from the closed sections, and the rate of permeation was measured.

From the results, it was clear that the rate of permeation had to be reduced to less than one-third that of the current system to meet the regulatory limit of less than 54 mg/day. The reduction target of the tank shell was set as 1/5, and the tube target was set as 1/10. In addition the numerical target needed for each component to comply with the overall regulatory value was determined.

The five elements of technology that are required to reduce the permeation of fuel tank systems were studied.

As is evident from Fig. 2, these five elements (four components) account for about 90% of the total permeation quantity. Modification of these elements is expected to bring good results in reducing the permeation.

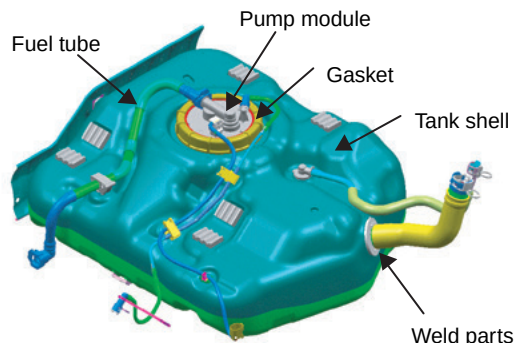


Fig. 1 Fuel tank system

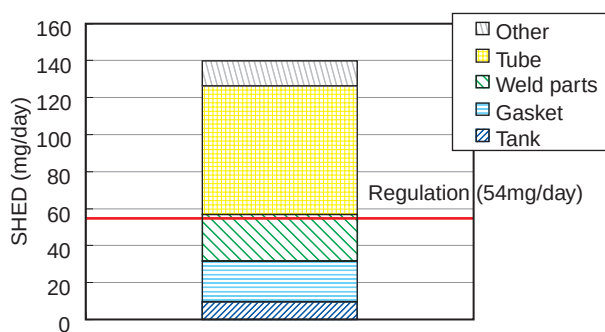


Fig. 2 Evaporative emissions from current fuel tank system

2.1. Tank Shell

The material composition in the fuel permeation barrier layer (hereafter referred to as “barrier layer”) of the plastic fuel tank was modified. In addition the thickness of the barrier layer was changed.

2.2. Plastic Tube Material

The barrier material of the plastic tube was changed to low-permeation polyphenylene sulfide (hereafter referred to as “PPS”), alloyed for higher flexibility in order to satisfy tube functions.

2.3. Reduction in Permeation of Pump Gasket

The pump gasket material was changed from the conventional NBR-PVC material to a fluorine-based material, increasing the initial tightening force and satisfying sealing performance.

2.4. Reduction in Permeation of Welded Child Parts

To restrict the permeation from welded child parts on the tank body, the child part materials were changed, and the welding conditions optimized.

2.5. Integration of Welded Child Parts

Welded child parts that could be integrated in the pump module were integrated, reducing the number of welded child parts, and thereby lowering the rate of permeation.

Among the five elements mentioned above, the new materials for tank shell and plastic tube are described here.

3. Tank Shell

3.1. Configuration of Fuel Tank Layers

As shown in Fig. 3, the plastic fuel tank has a 4-type, 6-layer configuration, and makes use of ethylene vinyl alcohol (hereafter referred to as “EVOH”) in the barrier material.

EVOH is a copolymer of ethylene and vinyl alcohol, and its structure is shown in Fig. 4. By changing component proportions, its permeation characteristics and mechanical properties can be changed⁽³⁾.

3.2. Reduction in Permeation of EVOH

The relationship between the proportion of ethylene in EVOH and the rate of fuel permeation is shown in Fig. 5.

Vinyl alcohol is polar, hindering molecules that try to permeate the tank wall. Thus, as the proportion of vinyl alcohol is increased, the barrier resistance of the EVOH material is enhanced^{(4), (5)}.

The ethylene content of EVOH for the PZEV tank shell was set at 24 mol%, which minimizes permeation to a manageable level and is suitable for the equipment currently used.

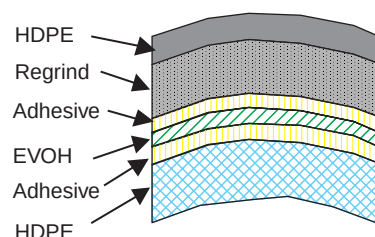


Fig. 3 Structure of fuel tank shell

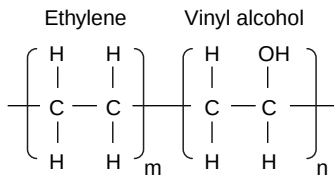


Fig. 4 EVOH structure

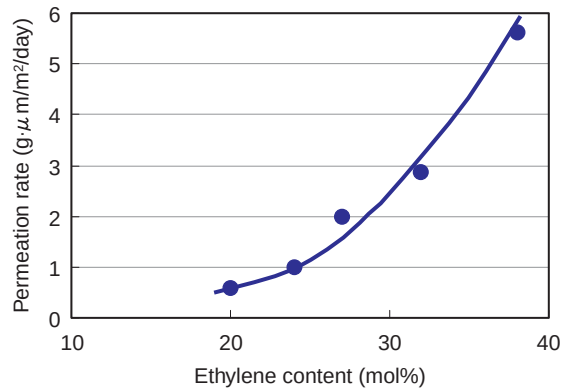


Fig. 5 Ethylene content vs. permeation rate

3.3. Optimization of Layer Configuration

Table 1 shows the basic properties of High Density Polyethylene (hereafter referred to as “HDPE”), the main component of the tank shell, and the basic properties of the barrier layer EVOH. EVOH is a harder material and has 1/50th the elongation as compared to HDPE.

The thickness of EVOH may be simply increased to reduce the rate of permeation from the tank shell, but issues such as impact strength reduction may be anticipated. Accordingly, tests were carried out to study the relationship between the thickness of the EVOH layer and the tensile impact strength of the tank shell. Tests were also carried out to study the relationship between the thickness of the EVOH layer and the rate of permeation. The results of both tests are shown in Fig. 6.

The rate of permeation can be reduced by increasing the EVOH thickness, but if the thickness increases above 4%, the impact value drops below that of the conventional configuration, which is the target value. Therefore, the thickness of the barrier layer of the plastic fuel tank for PZEV was set at 4% so that no reduction in impact strength occurs. If the EVOH thickness is reduced, the tensile impact strength does not change, but the rate of permeation increases. Therefore, the lower limit of the EVOH layer thickness was set at 2.5%.

Figure 7 shows the relationship between the position of the barrier layer and the rate of fuel permeation. It was observed that the highest permeation occurs when the PZEV barrier layer is located on the outside layer of the plastic fuel tank. The rate of permeation lowers as the barrier layer is positioned toward the inside of the tank, but due to restrictions with the current mass-production blow molding machine capability, the barrier layer position could not be located on the inside layer. Its location was finally moved in by 5% from its current location to 35% from the inside.

Table 1 General property of EVOH vs. HDPE

Item	Unit	HDPE	EVOH
Density	g/cm ³	0.95	1.19
Tensile strength	MPa	44	45
Elongation	%	>600	12
Flexural modulus	MPa	950	4770

3.4. Permeation from Tank Shell

Figure 8 shows the effect of the measures described above on the reduction of fuel permeation.

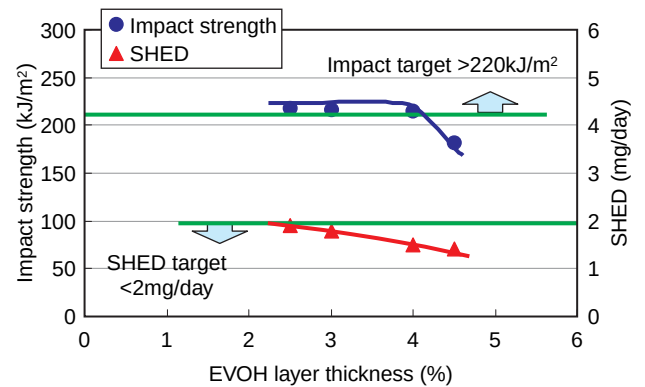


Fig. 6 EVOH layer thickness vs. impact strength and evaporative emissions

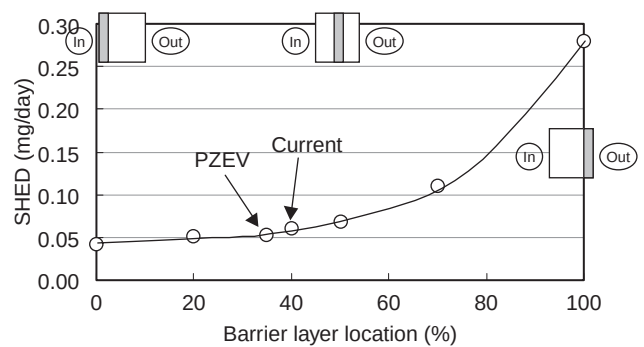


Fig. 7 Barrier layer location vs. evaporative emissions

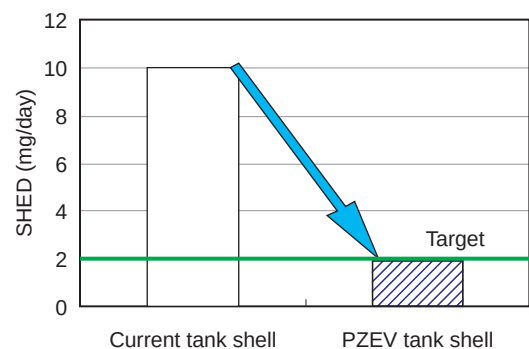
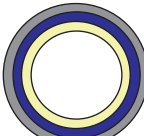
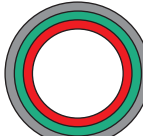
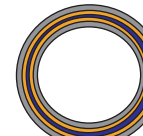


Fig. 8 Tank shell evaporative emissions

Table 2 Monitor material for low permeation tube

	ETFE	PPS	Polyester	Liquid crystal polymer	EVOH
Permeation resistance	Acceptable	Excellent	Excellent	Excellent	Good
Fuel resistance	Excellent	Good	Good	Good	Good
Chemical resistance	Excellent	Good	Acceptable	Good	Acceptable
Heat resistance	Good	Good	Acceptable	Good	No good
Flexibility	Good	Acceptable	Good	No good	Acceptable
Impact resistance	Good	Acceptable	Good	Acceptable	Acceptable
Total	Acceptable	Good	Acceptable	No good	No good

Table 3 Tube structure of present ETFE multi-layer tube and examined 2 types of low permeation tube

		ETFE multi-layer tube	PPS multi-layer tube	Polyester multi-layer tube
Structure				
Barrier layer		ETFE	PPS	Polyester
Number of layers		3	3	5
Layer composition	1 (Inner layer)	ETFE	PPS	PA11
	2	Adhesive	Adhesive	Adhesive
	3	PA11	PA11	Polyester
	4	—	—	Adhesive
	5 (Outer layer)	—	—	PA11

The plastic fuel tank shell permeation was reduced to one-fifth that of the conventional tank, and the target of less than 2 mg/day was achieved.

4. Tube Material

4.1. Selection of Tube Material

Since the target value was set at below 1/10th the conventional value for the plastic fuel tube, a barrier material with an extremely high permeation resistance was required.

Table 2 shows the results of the material evaluation for the barrier layer of the plastic fuel tube. The material evaluation included a comparative study of six parameters including permeation resistance, fuel resistance, chemical resistance, heat resistance, flexibility and impact resistance⁽⁶⁾⁻⁽⁹⁾.

Since PPS and polyester-based plastic materials provide a strong barrier as well as the heat resistance and flexibility required for the plastic tube application, the performance of these two materials in multi-layer tubes was further evaluated. Liquid crystal polymers have excellent barrier performance but flexibility and cost become issues; therefore, they were not studied for use in multi-layer tubes⁽¹⁰⁾.

PPS has benzene rings in the main chain, and has an inflexible molecular structure, resulting in poor impact resistance and flexibility as compared with conventional ethylene-tetrafluoroethylene (hereafter referred to as “ETFE”). Therefore, a modified PPS alloyed with an elastomer for enhanced flexibility was used as the barrier material. Figure 9 shows its Transmission Electron Microscopy (TEM) photograph. It can be observed that

elastomer regions of about 1 μm are dispersed uniformly as islands in the sea of PPS. Due to the addition of this elastomer, the Izod impact strength at -40°C was enhanced from 25 J/m to 202 J/m.

4.2. Layer Configuration of Multi-layer Plastic Tube

Table 3 shows the layer configuration of a multi-layer plastic tube in which PPS and polyester-based plastic were used as barrier materials.

The three-layer PPS tube was configured as follows: a modified PPS layer with high fuel resistance and barrier capacity as the innermost layer in direct contact with fuel, polyamide 11 (hereafter referred to as “PA11”) as the outermost layer (similar to the conventional ETFE multi-layer tube), and an adhesive layer between the two. The five-layer polyester-based plastic multi-layer tube was configured as follows: PA11 (which is used in a vapor-based single layer tube) as the innermost and outermost layers,

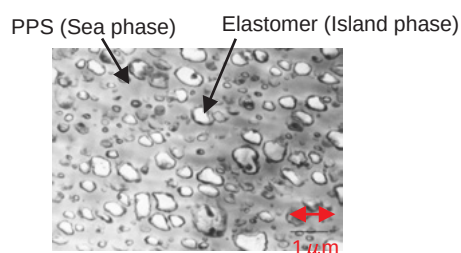


Fig. 9 TEM cross section photograph of PPS tube material

Table 4 Durability test results of multi-layer tube

Item	Tube type	Sour fuel	FUELC/E20	FUELC/M15	Brazil fuel
Cold impact	PPS multi-layer	Good	Good	Good	Good
	Polyester multi-layer	Good	Good	Good	Good
Cold bending	PPS multi-layer	Good	Good	Good	Good
	Polyester multi-layer	No good	No good	Good	Good
Adhesive force	PPS multi-layer	Good	Good	Good	Good
	Polyester multi-layer	No good	Good	Good	Good

polyester-based plastic (forming the barrier layer) as the intermediate layer, and two adhesive layers to bond them.

4.3. Evaluation of Fuel Resistance of Tube Material

Various fuels were used and durability tests were carried out to evaluate the fuel resistance of polyester-based plastic multi-layer and PPS multi-layer tubes. Table 4 shows the fuel types evaluated and the durability test results for each kind of fuel. Tests were carried out at 80 °C, which is the maximum guaranteed temperature on the vehicle body side.

The polyester-based multi-layer tubes developed cracks during low temperature bending tests with sour gasoline. Peeling occurred during adhesive tests using the same construction with sour fuel, and cracks occurred during low temperature bending tests using FUEL C/E20 (ethanol 20%). Figure 10 shows the tube cross section after the tests. Cracks were observed at the interface of the polyester-based plastic and adhesive layer. It was concluded that since polyester resin has ester bonds in the main chains, hydrolysis occurred during fuel immersion, and the material decomposed and deteriorated. From these results, multi-layer tubes with polyester-based plastic as the barrier material were concluded to be unsuitable for use as fuel tubes.

PPS multi-layer tubes satisfied the target performance with respect to all the evaluated parameters for various kinds of fuel. Figure 11 shows the condition of a PPS multi-layer tube cross

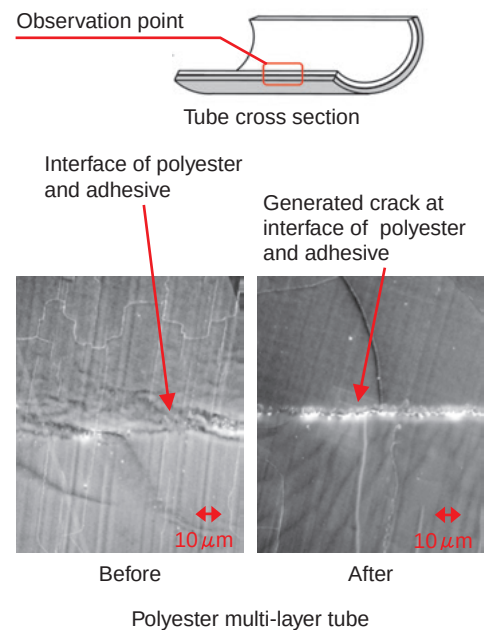


Fig. 10 SEM photograph of polyester multi-layered tube cross section before and after durability test

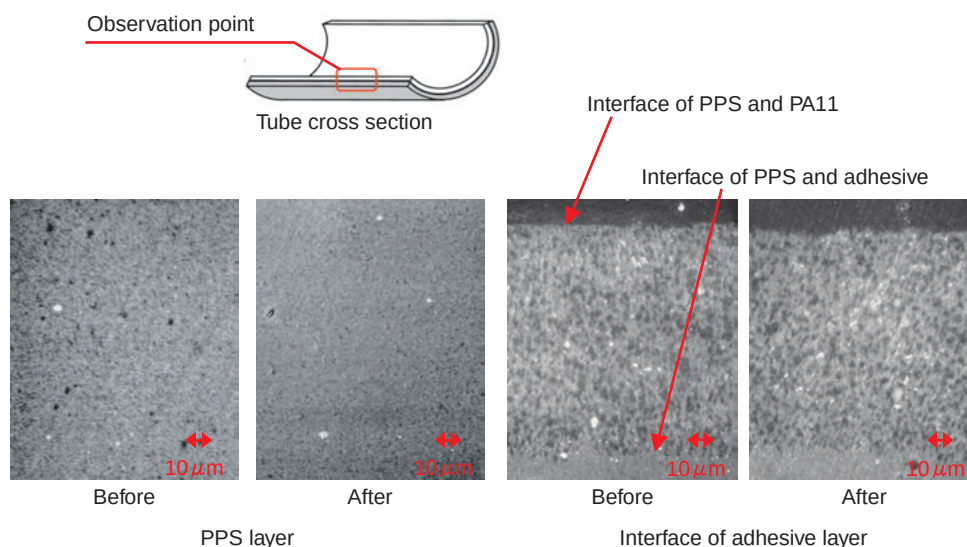


Fig. 11 SEM photograph of PPS multi-layered tube cross section before and after durability test

section. Observation of cross sections after durability tests showed no cracks or deterioration at the interface between the modified PPS resin surface and adhesive layer, confirming adequate fuel resistance and durability. In view of the above, a multi-layer tube with modified PPS as the barrier layer in the low-permeation plastic tube was used.

4.4. Permeation from Tube

Figure 12 shows the results of fuel permeation reduction with the PPS multi-layer tube developed at this time.

The permeation from the plastic tube was reduced to one-tenth that of conventional tubes, and the target of less than 0.6 mg/m/day was achieved.

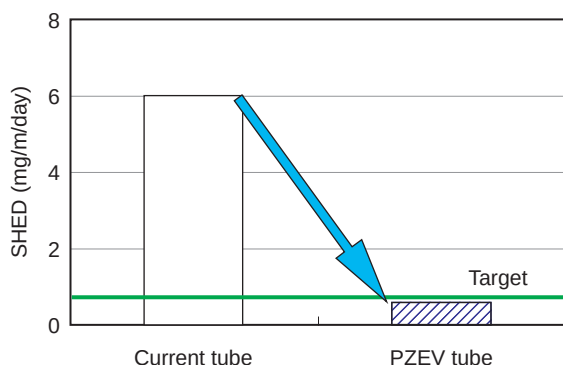


Fig. 12 Tube evaporative emissions

5. Compliance with PZEV Standards

Compliance with PZEV standards has been verified based on the rate of permeation of the fuel system. Test results using the SHED method with Phase III as the test fluid are shown in Fig. 13.

The rate of system permeation was below 54 mg/day as required by PZEV standards.

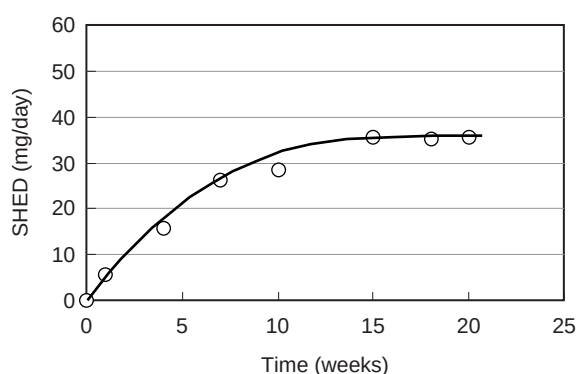


Fig. 13 Fuel system evaporative emissions

6. Conclusions

A plastic fuel tank system complying with PZEV standards was developed and fitted on the new CIVIC-IMA.

- (1) By using the newly developed plastic fuel tank barrier material, a permeation rate of less than 2 mg/day from the tank shell was achieved.

- (2) A modified PPS was used in the plastic tube barrier material and a permeation rate of less than 0.6 mg/m/day was achieved.
- (3) A permeation rate of less than 54 mg/day from the fuel system was achieved in SHED tests using PHASE III fuel.

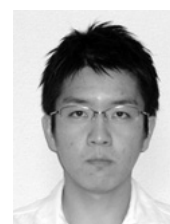
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