

Development of a Long Life Engine Coolant

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ABSTRACT

We have developed a long life engine coolant that has performance equivalent to current coolants with respect to impact on cooling system parts and anti-corrosion performance for extended metal life through the use of organic carboxylate, inorganic oxychloride inhibitors, and other compounds added in appropriate amounts.

Vehicles utilizing this coolant realized maintenance intervals more than two times longer than with current coolant. In addition, this maintenance reduction reduces the amount of coolant waste generated with regular replacement by approximately 70% or more, and makes it possible to reduce disposal costs and incineration volumes.

1. Introduction

Global concerns to reduce environmental waste load have led to increasing calls for recycling and reuse. In addition, the crucial issue of the cost for disposal of waste fluids remains. Further, demands are also being heard for reducing the maintenance costs associated with automobile ownership. Thus, there are strong needs for long life consumables. As one response to those needs, we set our sights on extending the longevity of various oils used in automobiles.

As shown in Fig. 1 as a result of revisions in control laws and systems of regular vehicle inspection, non-amine types of corrosion inhibitors were developed and adopted for use in automobile coolants. In the 1990s, maintenance intervals were set at 2-3 years after the initial application, but recently manufacturers have more commonly begun recommending intervals of once every five years.

In the face of such universal social needs, as well as

demands for extended coolant maintenance intervals, the current project aimed at the development of a long life engine coolant.

In this article, we introduce the development of this new coolant through a discussion of inhibitor longevity performance and anti-corrosion mechanisms, together with an evaluation of parts compatibility.

2. Development Objectives

Numerous demands are placed on the coolant used in internal-combustion engines,⁽¹⁾ as summarized below:

- (1) to prevent freezing of the coolant system passages under low-temperature conditions, or when used in cold-winter areas;
- (2) to maintain the temperature differential between the coolant and ambient temperature by the effect of raising the boiling point of the coolant;
- (3) to help prevent metal corrosion of the cooling system;
- (4) to be compatible with the various parts used in the cooling system.

Of these demands, (1) and (2) are innate characteristics of the combination of the coolant's basic ingredients ethylene glycol (EG) and water, and have no impact on the longevity of the fluid. On the other hand, (3) and (4) are decisive factors in coolant longevity, with the result that we set the following development goals with regard to these two points:

- to produce a coolant that would provide corrosion prevention for at least twice as long as current coolants, at current coolant ratios;
- to suppress any adverse influences on cooling system parts to current levels.

	'85	'90	'95	'00
Law and technical history	● US ★ Toxicity examination of Inhibitor in EPA ('88-) ★ Acceptance of bitterness additive ('93-) ☆ Maintenance interval 2 years → 3-5 years	● JPN ★ Amine export regulation ('88-) (Amine LLC → Non-amine LLC) ☆ Maintenance interval 2 years → 3-5 years	● EU ★ Correspondence to non-amine ('87-)	
Maintenance interval tendency	2 years/30000-60000km	3 years/60000-100000km	5 years/100000-240000km	
Honda response	☆ Non-amine regulation conformance (Conventional LLC) ☆ Maintenance interval increase			

Fig.1 Coolant technical and maintenance history

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3. Extending Coolant Longevity

The basis for coolant maintenance interval settings is the deterioration of anti-corrosion performance. Thus, based on current coolants, we studied the anti-corrosion mechanism of current coolants, together with means of extending its longevity.

3.1. Analysis of Recovered Coolants

In order to understand trends in the deterioration of currently available coolants, we performed coolant sampling of currently operating vehicles. The sample totaled more than 300 vehicles from all over the world.

(1) Inhibitor changes

Figs. 2 and 3 portray examples of changes over time to the inhibitor within actual automobiles. Inside an automobile, inhibitors are exposed to heat, metals, and polymers, subjecting them to deterioration and adsorption, resulting in substantial volumetric decline from their initial levels. From our analyses of these phenomena, we learned that inhibitors can be divided into inorganic acids which are consumed quickly, and organic acids which undergo almost no change in level over long periods of time. Based on these facts, we discovered that the use of organic acid inhibitors is effective in extending the longevity of coolant anti-corrosion properties.

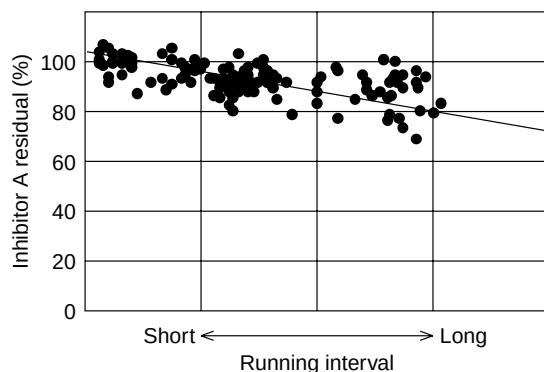


Fig.2 Market deterioration of conventional Honda Genuine coolant inhibitor A

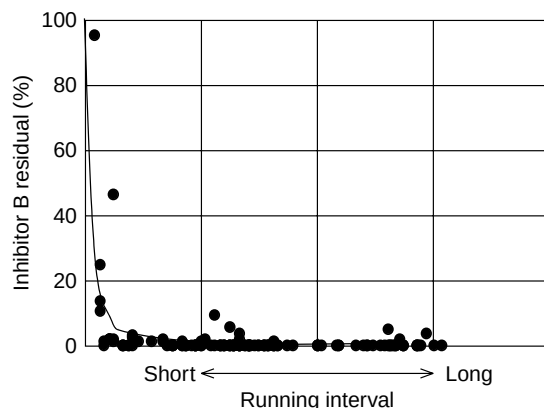


Fig.3 Market deterioration of conventional Honda Genuine coolant inhibitor B

(2) Changes in by-products of degradation

When the ethylene glycol comprising the basic coolant ingredient degrades, it changes into its by-products, formic acid and glycolic acid,⁽²⁾ but these cause a lowering of the solution's pH, leading to corrosion. The causal factor in this degradation is high-temperature oxidation caused by heat, dissolved oxygen and contact with metal.

We then examined time-based changes in the production of degradation by-products in currently used coolants. The results of that study are shown in Fig. 4. These results show that by-products of degradation increase in direct proportion to elapsed engine operating time. In sum, we learned that to prevent degradation, it was necessary to formulate a coolant with pH buffering properties capable of suppressing oxidation.

(3) Changes in Metal Ions

Next, we studied changes in metal ions released over time. Fig. 5 depicts the volume of aluminum (Al) ion generated, while Fig. 6 depicts the same for copper (Cu) ions generated. The results showed only slight generation of aluminum ions, while the volume of copper ions produced tended to rise with long elapsed operating times. As a result, we learned that one issue in extending the longevity of current coolants is the necessity of extending the coolant's ability to resist copper corrosion.

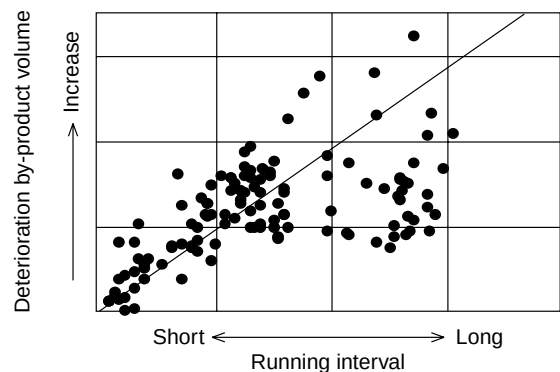


Fig.4 Market behavior of by-product in engines using conventional Honda Genuine coolant

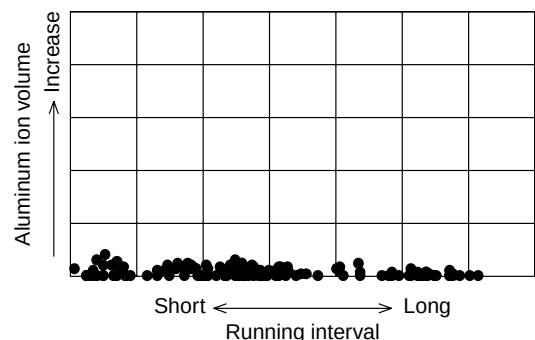


Fig.5 Aluminum ion occurrence in engines using conventional coolant

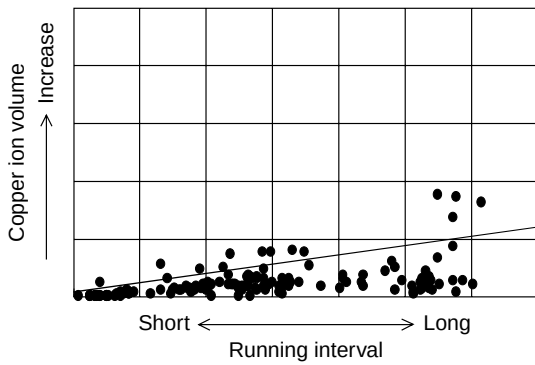


Fig.6 Brass ion occurrence in engines using conventional coolant

4. Consideration and Evaluation of a New Formula Coolant

When formulating the ingredients for a new coolant, we focused on the three points noted above, namely, use of long life inhibitors, improvement of pH buffering performance, and extending the longevity of the coolant's copper corrosion resistance.

Specifically, we selected a coolant based mainly on an organic acid inhibitor, also possessing heat-resistance, corrosion resistance, and compatibility with coolant system

	Metal appearance after being dipped in coolant					
	Aluminum	Cast Iron	Steel	Brass	Solder	Copper
Organic acid prototype coolant						
Weight loss toughness	OK	OK	OK	OK	OK	OK
Current coolant						
Weight loss toughness	OK	OK	OK	OK	OK	OK

Fig.7 Metal corrosion test using the organic acid prototype and the current coolant

	Radiator lower tank after operation
Organic acid prototype coolant	
Current coolant	

Fig.8 Parts recovered from each engine test using the organic acid prototype and the current coolant

materials. In our selection, we spent the most time confirmation testing all metal parts throughout the coolant circulation system for anti-corrosion efficiency under circulating conditions, anti-cavitation corrosion characteristics, and changes in the physical properties of polymers.

4.1. Evaluation of Metal Corrosion Resistance

Selecting the optimum organic acid as our long life inhibitor, we formulated a prototype organic-acid type coolant and then evaluated the prototype's corrosion-prevention properties. The results of our metal corrosion testing are shown in Fig. 7, while results from parts collected after bench testing are shown in Fig. 8 compared with the existing coolant.

According to these tests, no unnatural phenomena could be detected using currently available conventional coolants. On the other hand, laboratory tests of metal corrosion using the prototype coolant resulted in some blackening of the aluminum sample, but the prototype still appeared good, producing no change in mass. When parts from actual vehicles were recovered and examined, however, whitish sediment was found. An analysis of the sediment showed it to be aluminum salts resulting from corrosion produced within the engine environment.

As a countermeasure, we changed the inhibitor. To measure initial corrosion resistance, we, for example, set up a circulation corrosion test which could simulate the conditions of an actual engine, and thus formulated a new coolant which could maintain the anti-corrosion function for aluminum parts.

To evaluate the new coolant's anti-corrosion performance, we performed anti-corrosion tests for aluminum heat-transfer surfaces⁽³⁾ as shown in Fig. 9; the results of the Circulation Corrosion Test are shown in Fig. 10. As indicated in Fig. 9, we confirmed no remarkable discoloration or aluminum ion elution. Fig. 10 shows that under the conditions of coolant circulation, the new coolant possesses good aluminum anti-corrosion properties. On the other hand, the aforementioned prototype organic acid coolant did not possess sufficient aluminum corrosion prevention properties, and significant blackening and coolant flow erosion could be detected on the aluminum heat-transfer surfaces.

Coolant	New coolant	Organic acid prototype coolant
Appearance		
Weight loss by corrosion	No problem	No problem
Aluminum anti blacking	Good	Bad

Fig.9 Anti-corrosion performance on aluminum heat-transfer surfaces

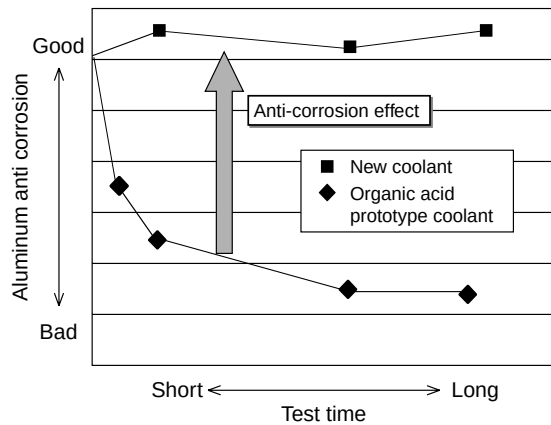


Fig.10 Circulation corrosion test results

4.2. Compatibility with Polymer Materials

Since it is difficult to suppress polymer oxidation degradation through the deliberate use of additives, it is necessary to evaluate the formulated coolant's resistance to polymer degradation and to confirm that it presents no adverse impact on polymer service life. To test this property of the coolant, we used rubber and nylon resin parts as our polymer materials for testing. One example of each of these is shown in Figs. 11 and 12.

In the case of rubber parts, we confirmed that the newly formulated coolant's compatibility with rubber is equivalent to current conventional coolants in terms of changes in hardness, volume, elongation, and tensile strength. Further, nylon radiator parts likewise demonstrated no change in their fulfillment of minimum creep resistance standards, confirming that they are not adversely influenced in terms of their ability to withstand heat and pressure.

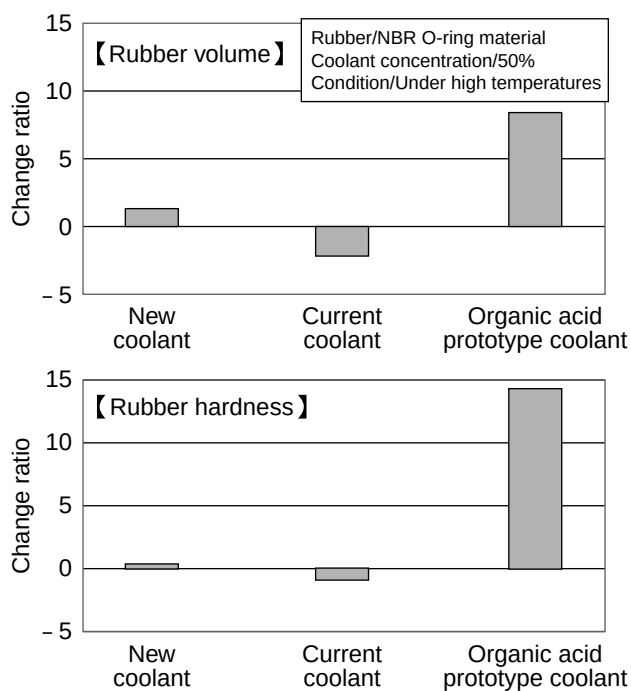


Fig.11 Coolant performance with rubber

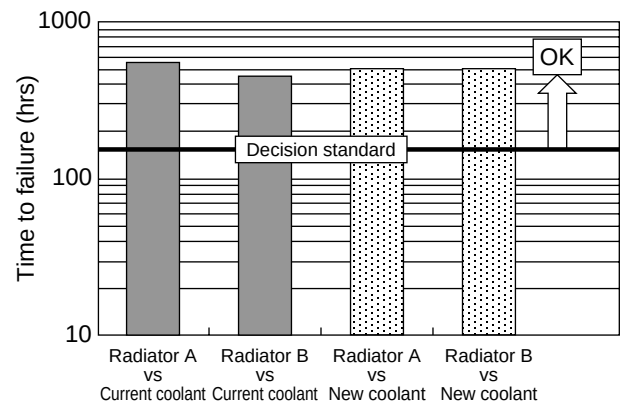


Fig.12 Creep performance of plastics radiator tanks

4.3. Compatibility with Cooling System Parts

Before adopting a new coolant, it is necessary to confirm that the coolant is fully compatible with all the parts composing the cooling system.

In particular, the water pump must be able to circulate the coolant while remaining sealed, and of all the parts of the cooling system, the mechanical seal at the pump's core is considered the most sensitive to new coolant formulas.⁽⁴⁾ Fig. 13 depicts the mechanism of leakage from the sliding surfaces of the pump. Fig. 14 shows the results of an evaluation of the sealing characteristics of the rotating

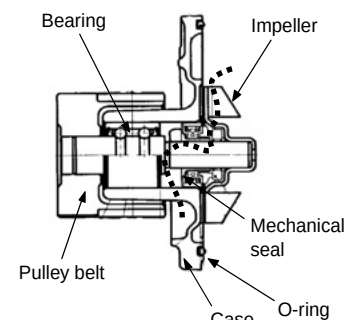


Fig.13 Water pump coolant leak mechanism

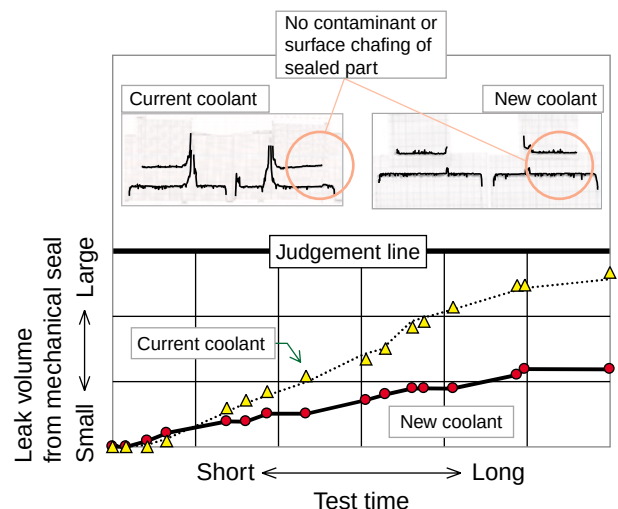


Fig.14 Compatibility of the new coolant with the water pump mechanical seal

mechanical seal when considered in isolation. From this, it can be seen that the new coolant formula demonstrates performance equivalent to conventional coolants in fulfilling the minimum criteria for coolant leakage with no damage to seal performance. It also demonstrated no problem of contaminant buildup or chafing on the mating ring and seal ring sliding surfaces, allowing us to determine that it fulfilled all requirements for compatibility.

4.4. Road Test Results

Next, a vehicle engine was used to test for overall engine compatibility, the results of which are shown in Figs. 15-17. Fig. 15 displays photographs of the engine water jacket. The photographs show no corrosion on the aluminum heat-transfer surfaces, indicating good anti-corrosion properties. Fig. 16 is a cross-section cutaway of one part of the water outlet made to expose the surface layer. The new coolant demonstrates no noteworthy corrosion pitting, and based on the analysis indicated in Fig. 17, it can be confirmed that the surface aluminum oxide film has been maintained,

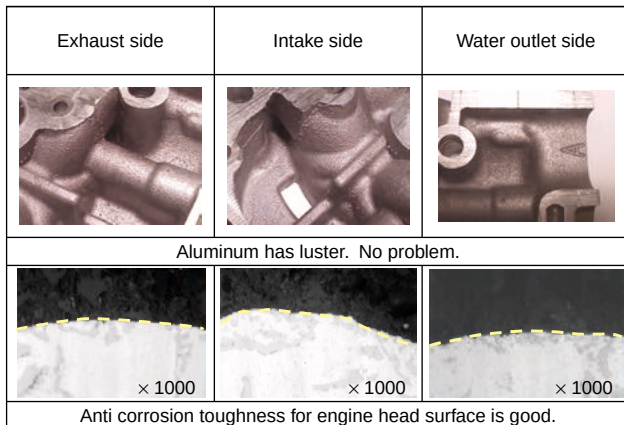


Fig.15 Heated surface condition of the engine head after bench testing using the new coolant

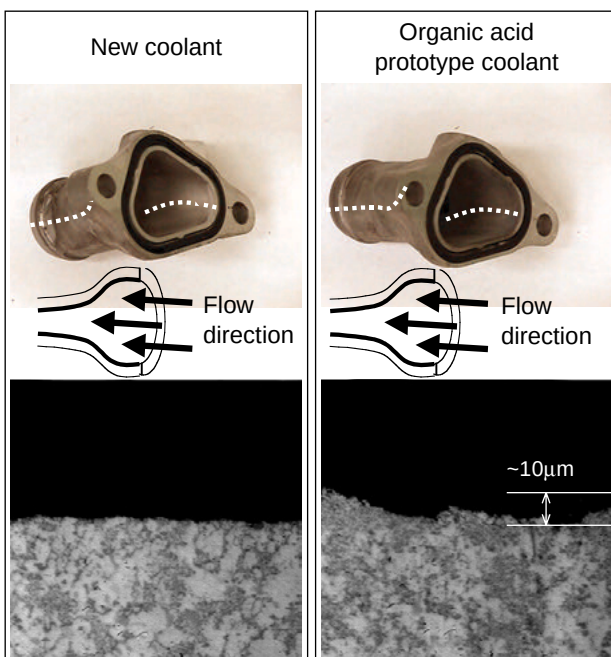


Fig.16 Surface section of water outlet area

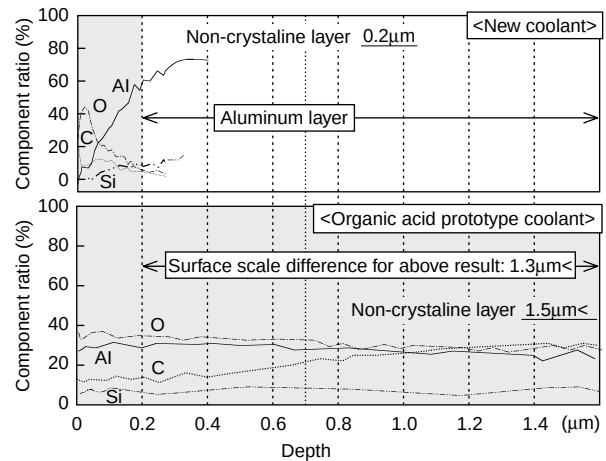


Fig.17 Element composition of the layers on the water outlet surface

indicating excellent compatibility with engine parts. On the other hand, the prototype organic acid coolant provided as a control demonstrates advancing corrosion of the surface aluminum, a sign of coolant flow erosion.

4.5. Results of Endurance Evaluations and Longevity

While confirming the initial performance characteristics of the new coolant fluid, we also performed corrosion testing to consider the load on an actual vehicle to evaluate potential coolant degradation. Table 1 shows anti-corrosion results when metal is soaked in coolants aged to a condition equivalent to 10 years old. According to these results, the new coolant formula caused no corrosion as demonstrated by gain or loss of metal volumes, for all the metals present in the cooling system, including aluminum, cast iron, steel, solder, bronze, and copper, thus demonstrating excellent retention of its anti-corrosion performance.

Fig. 18 shows the results of a simulation of coolant degradation in an actual vehicle. Compared to currently available conventional coolants, the new coolant delivers more than twice the anti-corrosion service life. In addition, this fact should make it possible to extend the regular maintenance interval for coolant.

Table 1 Corrosion toughness for equivalent to a coolant used for roughly 10 years

	Alumi-num	Cast Iron	Steel	Brass	Solder	Copper
General organic acid type coolant	×	×	○	○	×	○
Current coolant	○	×	○	○	×	○
New coolant	○	○	○	○	○	○

○: Good anti-corrosion

×: Poor anti-corrosion

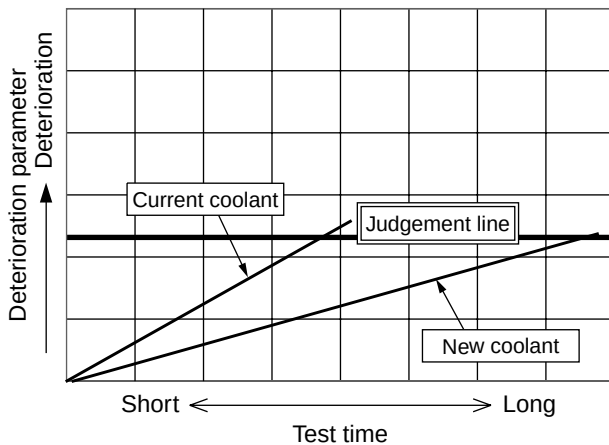


Fig.18 Long life performance of the new coolant compared with the current coolant

5. Effect of Reducing Discard Waste and Improved Quality

Finally, we calculated the effect that extended service life would have on reducing discarded coolant fluids throughout the world. These results are portrayed in Fig. 19. According to our calculations, based on 14-year automobile ownership with the same coolant fluid, the amount discarded would be reduced by 70% over current levels. As a result, by reducing the amount of such discard waste, switching from current conventional coolants to the newly developed coolant can be expected to contribute to a substantial lessening of environmental waste load and an economizing of resources.

Further, the extension of coolant service life means that it may be possible for users to merely make occasional additions to the engine coolant, avoiding the draining and changing of coolants throughout the entire life of the vehicle. This could promote higher performance through the avoidance of inferior aftermarket coolants and poor-quality water.

The newly developed coolant is planned to be installed on all new models from the 2001 model year, and its distribution will be expanded throughout the world.

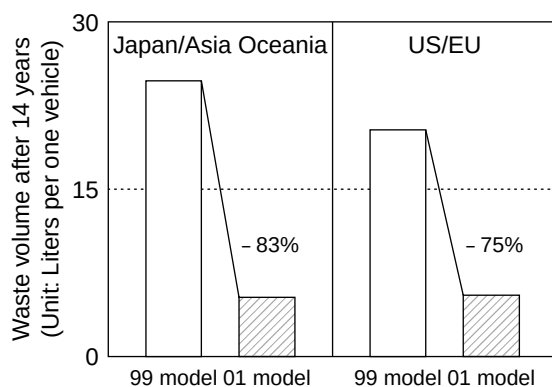


Fig.19 Coolant waste reduction volume through use of the new coolant

6. Conclusion

The current study can be summarized in the following points:

- (1) by adding appropriate amounts of organic carboxylate and inorganic oxychloride inhibitors, we were able to develop a new coolant with twice the metal-corrosion prevention performance of currently available conventional coolants;
- (2) we confirmed that the new coolant has compatibility to polymers and other parts of the cooling system equal to currently available coolants;
- (3) by using the new coolant, a reduction of more than 70% of the waste fluids represented by coolants could be achieved throughout the world (based on the assumption of 14-year automobile ownership).

7. Acknowledgments

We would like to take this opportunity to express our deep appreciation to coolant manufacturer C.C.I., Inc., and to the various manufacturers of cooling system parts for their cooperation in our formulation and compatibility testing.

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