

# The Effect of Viscosity Index on the Efficiency of Transmission Lubricants

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## ABSTRACT

The world is firmly focused on reducing energy consumption and on increasingly stringent regulations on CO<sub>2</sub> emissions. Examples of regulatory changes include the new United States Environmental Protection Agency's (U.S. EPA) fuel economy test procedures which were required beginning with the 2008 model year for vehicles sold in the US market. These test procedures include testing at higher speeds, more aggressive acceleration and deceleration, and hot-weather and cold-temperature testing. These revised procedures are intended to provide an estimate that more accurately reflects what consumers will experience under real world driving conditions. The U.S. EPA has also proposed changes, which will extend at least to 2016, that will increase the fleet wide corporate average fuel economy (CAFE) standards step wise, year on year and would impose limits on the amount of greenhouse gas emissions.<sup>3,8</sup>

Typical operating temperatures in automatic transmissions during cold start-up and light-duty operation are between -20°C and 80°C. Temperatures during severe-duty intervals, such as towing, can be higher than 100°C. Recently, there has been a trend to make automatic transmission fluids (ATFs) with lower kinematic viscosities (KV) in the interest of improving fuel economy by improving the mechanical efficiency of the transmission. Unfortunately, the use of lower viscosity fluids can lead to gear and bearing durability problems among myriad other problems. Without making significant hardware changes the lower practical viscosity limit has been estimated to be about 5.0 cSt.<sup>4-7</sup> If decreasing the 100°C KV isn't always practical or possible, what else can be done to improve efficiency? One option is to keep the fluid viscosity low as possible under normal operating conditions for improved efficiency, and under high-temperature conditions, keep the viscosity as high as possible to maintain hydraulic

system, pump, seal and clutch performance. Fluids with very high viscosity indices (VI) approach these viscometric properties. Both an increase in mechanical efficiency and fuel economy will be demonstrated in a comparison between a very high VI fluid and a lower VI fluid, where both fluids have the same KV at 100°C.

## INTRODUCTION

Beginning with the 2008 model year, the United States Environmental Protection Agency (U.S. EPA) revised its fuel economy test procedures for vehicles sold in the US market. The revised procedures are intended to provide an estimate that more accurately reflects what consumers will experience under real world driving conditions. These changes include testing at higher speeds, with more aggressive acceleration and deceleration, and in cold temperatures. The U.S. EPA expects the new procedures to reduce city fuel economy ratings by an average of 12% and highway ratings by an average of 8%.<sup>8</sup>

The United States Government is now proposing tougher fuel economy standards and the nation's first rules for tailpipe emissions of greenhouse gasses for new vehicles. The new fuel economy standards — similar to what California has been trying to enact since 2002 — would push the corporate average fuel economy (CAFE) requirement to a fleet wide average of 35.5 miles per gallon by 2016, four years ahead of the schedule the United States Congress laid out in a 2007 energy law. The proposed rulemaking will be a joint effort between the U.S. EPA and the Department of Transportation and will mandate a 5% annual increase in fuel economy for model years 2012 through 2016. It would also require cars to get an average of 39 mpg and light trucks 30 mpg as well as limit the amount of greenhouse gas emissions from passenger cars and light trucks to 250 grams per mile per vehicle in 2016.<sup>3</sup>

The automobile and lubricant industries, responding to these legislative demands, consumer pressures regarding fuel prices and an increasing environmental consciousness, are looking for opportunities to increase fuel economy in vehicles.

The lubricant industry is developing fluids that help increase mechanical efficiency and, in principle, fuel economy. One way for the lubricant can improve mechanical efficiency is to reduce the losses incurred by churning and pumping of the fluids in the automobile. To help reduce these losses, fluid kinematic viscosity (KV) should be as low as possible under normal operating conditions. Under high-temperature conditions, the fluid should have a KV sufficiently high for proper hydraulic system, pump, seal, and clutch performance. Fluids with very high viscosity indices (VI) (i.e. > ~230) achieve these viscometric properties better than fluids with more traditional VIs (~175). Figure 1 illustrates the potential increase in operating range of a relatively high VI fluid compared to a conventional VI fluid.

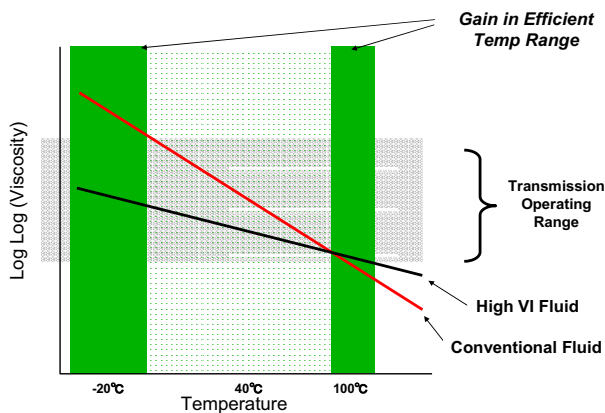


**Figure 1.** Illustration of the effect of VI on the effective operating range of a fluid

In this paper the results of a continuing study on the affects of ATF viscometrics on AT mechanical efficiency and vehicle fuel economy will be reported.<sup>1,2</sup>

**HIGH VI FLUIDS WITH NEW VISCOSITY MODIFIER ARCHITECTURE**

In the 1990's and early 2000's automatic transmission fluid (ATF) viscosities were around 7.2 cSt at 100°C. In the past several years there has been a trend by OEMs is to specify fluids with lower KV's at 100°C in order to improve the mechanical efficiency of the transmission and the fuel economy of the vehicle. To illustrate this point, Table 1 lists the viscometric properties of seven OEM factory fill and/or service fill ATFs and includes three comparisons of old and current fluids. Also listed for reference is the year the fluid specification changed. Significant emphasis has been placed on the KV at 100°C; smaller emphasis, seemingly, has been placed on KV's at lower temperatures. This is seen in the VIs of the fluids.

| OEM   | Chrysler® | Toyota® |         | GM®         |            | Ford®     |            |
|-------|-----------|---------|---------|-------------|------------|-----------|------------|
| Fluid | MS9602    | T-IV    | WS      | Dexron® III | Dexron® VI | Mercon® V | Mercon® LV |
| Year  | Current   | 2004    |         | 2006        |            | 2005      |            |
| 100°C | 7.4 cSt   | 7.1 cSt | 5.4 cSt | 7.1 cSt     | 6.0 cSt    | 7.3cSt    | 6.0 cSt    |
| 40°C  | 34        | 35      | 24      | 35          | 30         | 34        | 29         |
| 20°C  | 73        | 88      | 52      | 81          | 72         | 79        | 68         |
| VI    | 207       | 170     | 175     | 171         | 155        | 188       | 175        |

**Table 1.** Viscometrics for seven OEM factory fill ATFs

In most cases where the KV at 100°C was reduced the VI also decreased. Had the VI been maintained, or increased, the KV at lower temperatures would have been lower, potentially further improving efficiency of the transmission. This is illustrated by comparing the Toyota T-IV to WS. The VI was increased slightly resulting in a relatively significant 20°C KV difference. Yamamori-san *et al.* from Toyota measured and published the significant fuel economy gains they achieved from this change.<sup>7</sup> This group also reported that the reduction in KV was accompanied by a reduction in durability of gears and bearings which they overcame by increasing the base oil viscosity of the ATF.

Recently, this emphasis on KV at 100°C has been decreasing and more effort is being put toward reducing the KV at lower temperatures. Several OEMs have adopted KV at 20°C as a benchmark.

ATFs require a fine balance of many performance characteristics to achieve the desired overall performance. Viscosity index improvers (VII) are designed to impart the correct temperature/viscosity relationship so lubricants perform adequately within an expected operating temperature range. Until recently only two VII parameters had been typically adjusted to achieve maximum performance: molecular weight (MW) and the basic polymer chemistry, i.e. backbone and side-chain compositions. Higher MW VIIs are known to impart high VIs and they also allow the lowest treat rates, thus are often advantageous commercially. However, high MW VIIs are also more prone to mechanical shearing. So the MW must be adjusted to give the highest amount of thickening possible while still meeting the shear stability requirements of the fluid for the application. This trade-off makes it difficult to maximize both the VI and the shear stability; one traditionally was sacrificed for the other until a suitable compromise was reached.

Controlled formation of a VIIs architecture has been shown to give fluids with significantly increased VI, all else being the same. For example, a VII with a star-branched architecture can give very high VI boost while maintaining shear stability.<sup>9,10</sup> Table 2 offers a comparison of a traditional linear PMA and two star PMAs. In these blends the base oil composition was kept constant to demonstrate the advantages of this architecture. The VIIs were diluted in a conventional base oil comparable to the blend oils for ease of handling.

Therefore little effect is expected from the oil added with the VII. These blends were formulated to approximately the same 100°C KV. The polymer amounts (% w/w) are shown to allow direct comparison of the polymer architectures.

Using a star PMA (VII1) resulted in a blend that gives comparable shear loss to the standard formulation using a conventional PMA. While the shear stability is similar, the VI is greater and the Brookfield viscosity at -40°C is lower. Both of these properties are advantageous in ATF formulations.

The thickening ability of these VIIs is significantly higher than a typical conventional PMA VII. At approximately the same blend shear stability and KV at 100°C Fluid 1 contains 6.75% polymer whereas the standard formulation contains 9.25% polymer.

Fluid 2 demonstrates that further improvement in VI and Brookfield viscosity can be obtained by using a higher molecular weight star PMA. This, of course, comes at the expense of reduced shear stability. However, comparing the thickening and shear stability of blend fluids 1 and 2 to the standard formulation it is clear that the architecture changes the thickening/shear relationship advantageously.

|                                    | Standard Formulation | Fluid 1 | Fluid 2 |
|------------------------------------|----------------------|---------|---------|
| G-III Base Oil, 3 cSt @ 100° C     | 70                   | 70      | 70      |
| G-III Base Oil, 4 cSt @ 100° C     | 30                   | 30      | 30      |
| Performance Package (%w/w)         | 7.7                  | 7.7     | 7.7     |
| Pour Point Depressant (%w/w)       | 0.15                 | 0.15    | 0.15    |
| Standard PMA VII (%w/w polymer)    | 9.25                 |         |         |
| Star PMA VII1 (%w/w polymer)       |                      | 6.75    |         |
| Star PMA VII2 (%w/w polymer)       |                      |         | 4.70    |
| KV @ 100° C (cSt)                  | 7.53                 | 7.61    | 7.48    |
| KV @ 40° C (cSt)                   | 34.0                 | 32.9    | 27.6    |
| VI                                 | 199                  | 212     | 260     |
| Brookfield Viscosity @ -40° C (cP) | 9920                 | 8770    | 7090    |
| 20 hr KRL (% Viscosity Loss)       | 13%                  | 15%     | 20%     |

**Table 2.** ATF blends comparing two star PMA VMs to a conventional PMA VM in a typical ATF formulation.

## TRANSMISSION EFFICIENCY TESTING

To demonstrate the efficiency gains that can be achieved with a high VI fluid, two demonstration fluids were formulated. One fluid was formulated to a very high VI (251) and one to a more typical VI (183). Both fluids were formulated to 7.0 cSt at 100°C. Both contained the same performance package chemistry and had the same shear stability. To achieve the desired viscometrics and shear stability, the base oil composition was varied as shown in Table 3. Active polymer content was comparable between the two blends, at 4.6% and 4.7%. The impact of the VI difference can be seen in the

significant differences in KV's at the lower temperatures. See Table 3.

Figure 2 shows the measured KV with respect to temperature for these two fluids. At lower temperatures the KV of the high VI fluid is increasingly lower than its low VI counterpart.

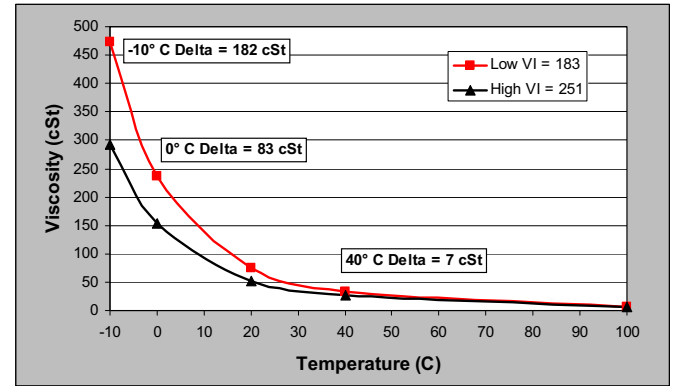


**Figure 2.** KV vs. Temperature for the two test fluids

|                                          | Low VI | High VI |
|------------------------------------------|--------|---------|
| Group III Base Oil, 3 cSt @ 100° C       | 51.6   | 75.3    |
| Group III Base Oil, 4 cSt @ 100° C       | 30.3   |         |
| Performance Package %w/w                 | 11.4   | 11.4    |
| Standard PMA VII %w/w polymer            | 4.6    |         |
| Controlled Architecture VII %w/w polymer |        | 4.7     |
| KV @ 100° C (cSt)                        | 7.0    | 7.0     |
| KV @ 40° C (cSt)                         | 33     | 26      |
| KV @ 20° C (cSt)                         | 75     | 51      |
| KV @ 0° C (cSt)                          | 237    | 154     |
| KV @ -10° C (cSt)                        | 474    | 292     |
| Brookfield Viscosity @ -40° C (cP)       | 11900  | 5040    |
| Viscosity Index                          | 183    | 251     |
| 20 hr KRL (Viscosity Loss)               | 16%    | 17%     |

**Table 3.** ATF blends prepared to test the effect of VI on fuel economy

An in-house, custom built AT efficiency test rig was used to measure relative torque losses in a 6 speed rear wheel drive type passenger car automatic transmission unit. The transmission was connected to a drive motor and two absorbing motors in a T-shape configuration, as shown in Figure 3. The transmission was fully drained and flushed a total of four times between fluids to achieve a complete flush with no measurable carry-over.

The rig was modified to allow both the transmission and the fluid to be cooled to approximately -10°C as shown in Figure 4. Fluid temperature, measured in the sump, was allowed to rise naturally as the test progressed.