Energy-inefficient tire construction and sub-optimal inflation can adversely impact EV range. (Geely)

> «Over the vehicle's life, a variable tire rolling-resistance coefficient could account for up to 4% battery-charge difference»

Tire pressure impact on EV driving range

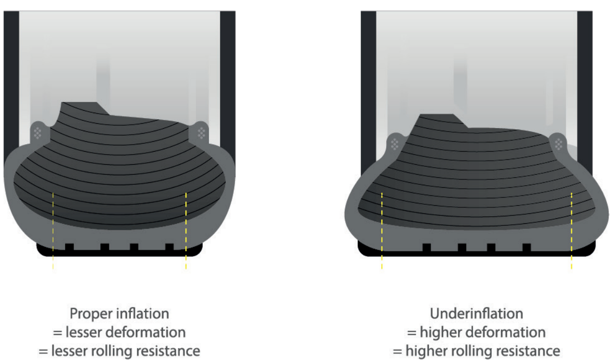
2020-10-07 LAMEI TANG; SHENG WEI; JEFFREY VALENTAGE; ZHENG LI; SUJITH NAIR

A new study shows that tighter control of tire-pressure loss can lead to marked improvement in electric-vehicle efficiency.

Electric-vehicle development teams have made great advances in improving vehicle range, mitigating "range anxiety" for the end customer. While much focus has been on advances in battery technology, controls and vehicle aerodynamics, electric-vehicle (EV) driving range also is significantly affected by tires. Tires lose a certain amount of air on a continuous basis. Energy-inefficient tire construction, sub-optimal inflation and other factors can adversely impact EV range.

Figure 1 shows that an underinflated tire is less stiff and its deformation is much higher, leading to a larger amount of heat dissipation and ultimately higher rolling resistance and poor range efficiency. A recent collaborative study by Geely Research Institute, Shanglong Linglong Tire Co. and ExxonMobil examined the effect of air loss (such as experienced after months of driving) on the tire's actual rolling resistance – and the subsequent effect on an EV's range. Results from the study will help determine tire specification for Geely Auto Group's next generation of EVs.

Figure 1: Difference in deformation between properly inflated tires and underinflated tires



Inner liner's critical role

In examining several production tires, the survey showed that more than 48% had poor air retention (inflation pressure loss rates [IPLR] > 3%). This was typical. Only 6% of the tires had the best possible air retention (IPLR < 1.7%). It is difficult to design a tire that is entirely leak-proof. A simple approach to minimizing air loss from tires is by designing an effective inner liner, the thin layer responsible for air retention. Inner-liner composition and design are the most crucial factors affecting air retention.

Air loss is affected primarily by inner-liner compound permeability, the inner-liner thickness and end-point-to-toe distance (the point where the inner liner ends). Among these three factors, the biggest contributor to air loss reduction is permeability. For example, decreasing the inner liner end-to-toe distance by 50% (from 20 mm to 10 mm) and increasing thickness by 15% (0.65 mm to 0.75mm) deliver respective IPLR improvements of 10% and 18%. But reducing the permeability coefficient by 40% yields an IPLR improvement of 30%.

Conventional inner-liner compounds include bromobutyl and chlorobutyl polymers. To achieve superior performance, high-performance polymers such as brominated isobutylene-co-paramethylstyrene (BIMSM; trade name Exxpro™ specialty elastomer), should be used because they have a lower permeability than conventional halobutyl polymers.

Because air loss over time reduces inflation pressure, the "in-use" rolling resistance experienced in actual driving conditions can be higher, leading to lower fuel economy. Unfortunately, these aspects might not be captured in the laboratory tests for measuring rolling resistance coefficient (RRC). Geely Engineering is taking a more balanced approach when it comes to improving tires by focusing on the "in use" RRC to improve the experience of end-use customers.

Beyond pressure monitoring

In an early effort to help prevent catastrophic failures on the road due to severely underinflated tires (> 20% underinflation), tire pressure monitoring systems (TPMS) were implemented. Geely notes this is inadequate, as TPMS does not prevent consumers from driving with underinflated tires prior to the warning system being activated. In 2018, Geely initially released a version of TPMS with an IPLR trigger of < 3.5% and in 2019 a subsequent specification improvement of < 2.5% IPLR. With increased global market demand for EVs it has become more critical to focus on "in-use efficiency" rather than a laboratory-generated RRC data points.

For this study, four 215/50R17 passenger-car tires with different inner-liner designs and air-loss rates were manufactured at LingLong; all other specifications were identical. The inner liners ranged from low-performance conventional systems (70/30 BIIR/NR) with high air loss to the highest-performance inner-liner system (100 phr Exxpro™ 3563) with the lowest air loss (see Table 1). The IPLR is measured as per ASTM 1112.

When the inner-liner composition is changed from 70/30 BIIR/NR (Tire B) to 100 BIIR (Tire C), the IPLR is improved by 33%. Conversely, when inner-liner thickness is increased by 15% – from 0.7 mm (Tire A) to 0.8 mm (Tire B), the IPLR improvement is just 10%. This observation aligns with previous studies, in which the results emphasized the importance of improving inner- liner composition (impermeability) for better air retention.

Table 1: Tires Used in Study & IPLR Results

Tire ID	IL Comp	IPLR (%)	Predicted Pressure Loss (6months)-KPa	TMS Warning
A	70/30 BIIR/NR	3.16	76	Yes
B	70/30 BIIR/NR	2.89	70	Yes
C	100 BIIR	1.92	50	No
D	100 Exxpro™ 3563	1.73	45	No

Figure 2 shows that Exxpro 3563-based inner liners (Tire D) have the best IPLR performance – almost 40% lower than the control tire (Tire A). From previous studies conducted by ExxonMobil Chemical, it was found that the air loss of tires subjected to real-world conditions was around twice that obtained in static conditions in the laboratory. To predict air loss after six months, the IPLR values are multiplied by a factor of predicted pressure loss for the four tires, accounting for the measured IPLR and the dynamic conditions.

Not surprisingly, the six-month predicted pressure loss for tires with high IPLR (> 3.1 %, Tire A) is much higher than for tires with lowest IPLR (< 1.8, Tire D). It also is expected that the rolling resistance change for the tires with IPLR > 3.1% (Tire A) is much higher than for the tires with IPLR < 1.8% (Tire D). For "in-use" efficiency, it is expected that there is minimal change to the rolling resistance: as shown in Figure 3, the tire with the lowest IPLR gives the lowest change to the RRC after six months.

Enhancing range, reducing consumption

From Table 2, it can be observed that the range loss for the tires with IPLR > 3.1% (Tire A) is much higher than for the tires with IPLR < 1.8% (Tire D) and proportional to the calculated rolling resistance changes in six months. The plot of range loss with IPLR is shown in Figure 4, the tire with the lowest IPLR delivering the lowest average range loss (averaged over the year).

Figure 2: IPLR of experimental tires with different innerliner compositions & gauge

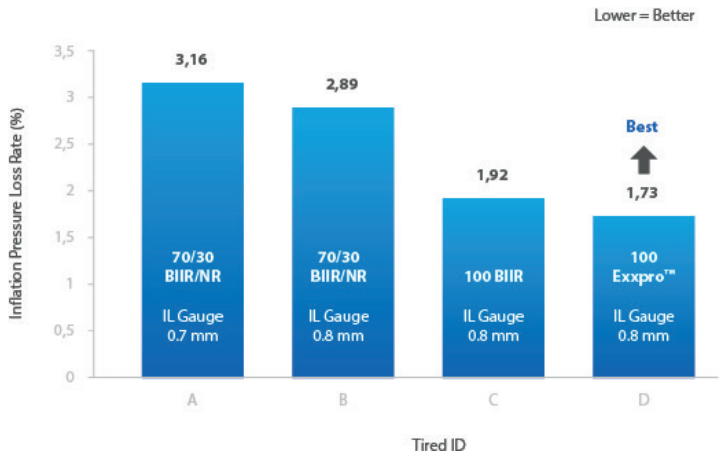


Figure 3: Simulated range loss correlation with IPLR

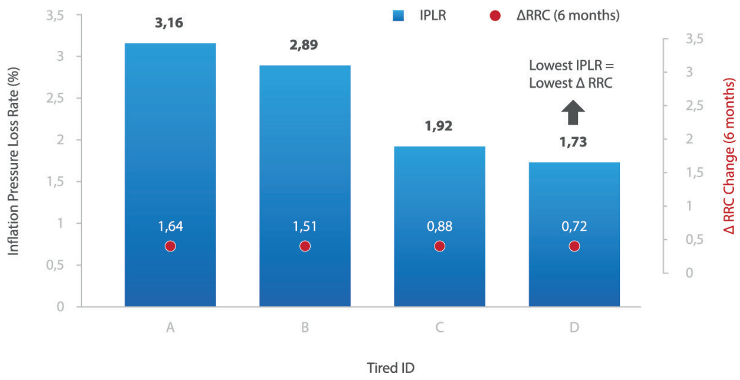


Figure 4: Tire inflation pressure and rolling resistance directly impacts EV driving range

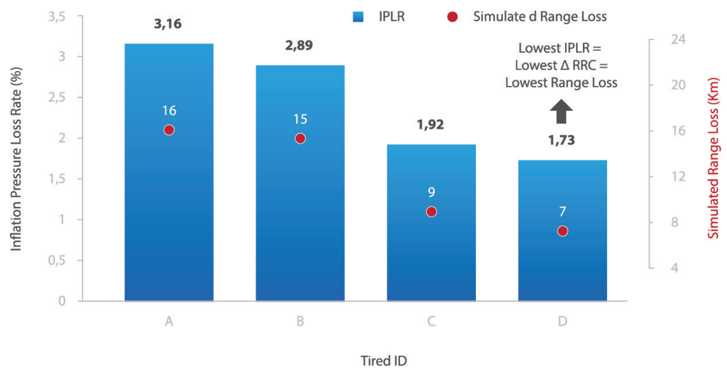


Table 2: RRC results & Simulated Range Loss Results

Tire ID	IPLR (%)	ΔRRC (6 months)	Range Loss (6 months, Km)
A	3.16	1.64	16
B	2.89	1.51	15
C	1.92	0.88	9
D	1.73	0.72	7

Figure 5: Simulated range predictions of vehicle equipped with tires having different IPLR

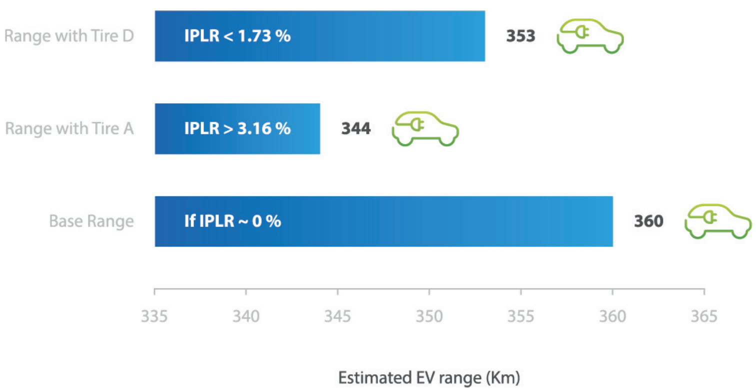


Figure 6: Calculated vehicle efficiency difference from tires with different IPLR

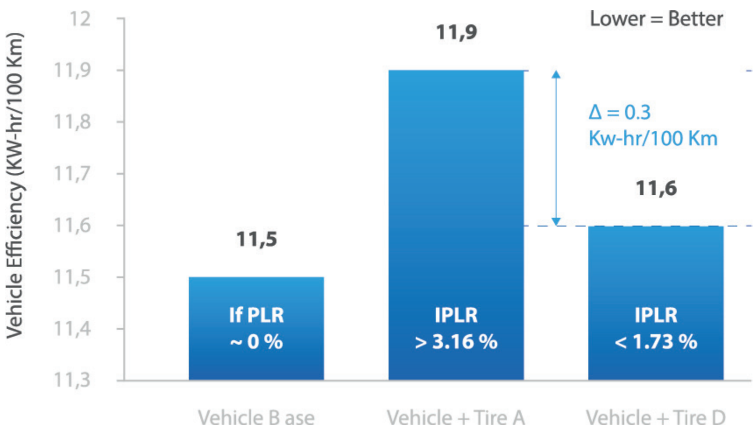
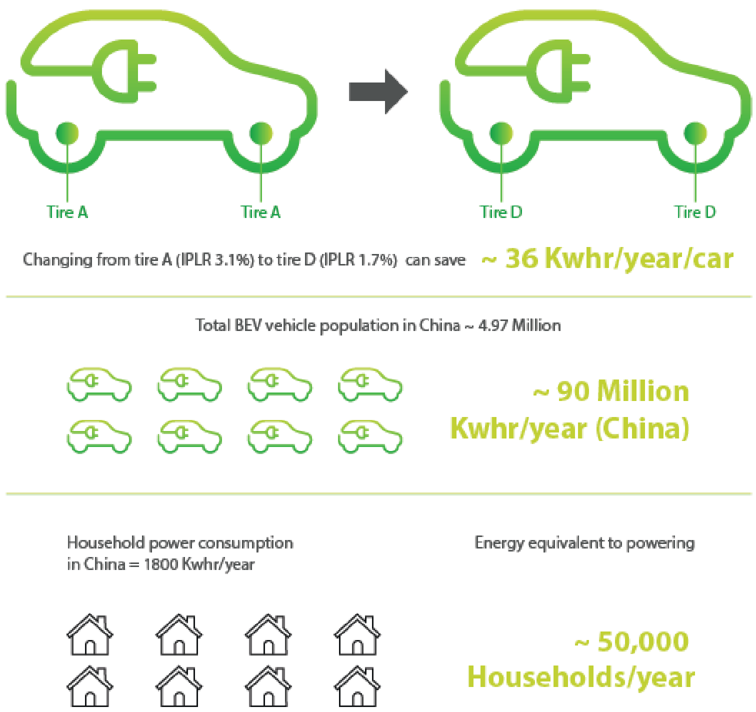


Figure 7: Implications of using tires with high & low IPLR – what does this difference in energy mean on a macroscale?



Range loss is highest for the tires with the highest IPLR (tire A) and lowest for the tires with the lowest possible IPLR (tire D). Figure 5 assumes a projected EV base range to be 360 km, possible only if the IPLR of the tires was near zero. Based on the study results, the actual average range would be 344 km with the use of high IPLR tires (> 3.1%) and around 353 Km with low IPLR tires (< 1.8%).

These results can be projected onto overall vehicle efficiency. In the theoretical vehicle's baseline, efficiency is close to 11.5 kWh/100 km (assuming the tires had an IPLR around 0 %). Due to the range loss from tire A (IPLR 3.16%), the efficiency is reduced to 11.9 kWh/100 km. When using Tire D (IPLR 1.73%), the efficiency is degraded to just 11.6 kWh/100 km. The energy wasted by using Tire A rather than Tire D is approximately 0.3 kWh/100 km (Figure 6).

Assuming an average vehicle travels 12,000 km (7456 mi) per year, the annual wasted energy difference between using these two sets of tires would amount to 36 kW-h. The total number of Chinese electrified-vehicle sales from 2012-2019 was around 7.54 million vehicles. Approximately 66% of these vehicles are BEVs (~4.97 million units). A simple tire change from Tire A to Tire D would save almost 90 million kW-h of electricity annually (Figure 7).

To understand the magnitude of this wasted energy, it is important to note that the annual energy consumption of an average household in China was ~1800 kW per hour per household. The difference in the amount of energy consumed between vehicles with tires with an IPLR of almost 3.2 and an IPLR of near 1.8 is the annual energy consumed by 50,000 Chinese households.

As the mobility sector shifts to electric-drive systems, maintaining consistent in-use performance will become more important. It is possible to lower tire IPLR via many routes – the most significant of these being via the use of polymers with the lowest permeability coefficient. The lower the IPLR, the lower the change in tire RRC over time, maximizing "in-use" EV driving range. Tire IPLR can be significantly improved to < 1.8% utilizing materials, tire designs and manufacturing equipment currently available to the industry.

Over the vehicle's life, a variable tire RRC could account for up to 4% battery-charge difference. Reducing IPLR and "in-use" RRC creates the potential for Tier-1 suppliers and OEMs to consider a lighter and/or less-expensive battery. And ExxonMobil Chemical road testing has demonstrated that EV range can be improved from 3-7% with optimized tire IPLR. In the future, we expect that an IPLR < 1.8% will be the target specification for class-leading EVs.

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