The Effects of Inflation Gas on Tire Laboratory Test Performance

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NHTSA Traffic Safety Facts, 2006*

- In 2006, there were an estimated 5,973,000 police-reported traffic crashes, in which:
  - 42,642 people were killed
  - 2,575,000 people were injured
  - 4,189,000 crashes involved property damage only
- Motor vehicle crashes are the leading cause of death for every age from ages 2 through 34
- From 1994 to 2004, NHTSA estimates that about 400 fatalities, annually (~1% of total motor vehicle fatalities), may be attributed to tire failures of all types

*NHTSA Traffic Safety Facts, 2006 Data, DOT HS 810 809, NHTSA’s National Center for Statistics and Analysis, Updated March 2008
Inflation of tires with $N_2$ gas is presumed to be beneficial. However, there are a wide variety of claims and counter-claims:

- Better inflation pressure retention
- Lower rolling resistance
- Better treadwear
- Lower running temperatures
- Better tire durability
- Less moisture
- Etc.
NHTSA Testing of Tires with Nitrogen Inflation

- NHTSA re-directed tires from other tire programs to address four basic questions:
  - Is there a systematic and quantifiable difference in the inflation pressure loss rate (IPLR) of tires when inflated with gases of varying nitrogen to oxygen ratios?
  - Are the observed differences in IPLR uniform among tires, or are they related to variables such as initial inflation pressure, or tire design and composition?
  - Are there direct effects of inflation gas composition on the rolling resistance of tires?
  - Are there differences in tire durability performance after accelerated aging with different nitrogen-to-oxygen ratios?
Testing

- In total, twenty-five different passenger or light truck tire models were inflated with:
  - Shop air with air line dryer
  - Dry N₂ gas from 94 to 99% purity
    - Initial purge and refill used
  - Gas composition measured at the beginning and end of test

- Tires were tested for:
  - Inflation pressure loss rate
  - Laboratory rolling resistance
  - Roadwheel endurance after oven aging
Under-inflated tires are a significant problem

- According to a NHTSA study, 27% of passenger cars and 32% of light trucks have at least one tire that is substantially underinflated*
  
  - “Operating a vehicle with substantially under-inflated tires can result in a premature tire failure, such as instances of tread separation and blowouts, with the potential for a loss of control of the vehicle. Under-inflated tires also shorten tire life and increase fuel consumption.” **

*Tire Pressure Special Study @ http://www.nhtsa.dot.gov/people/ncsa/

**U.S. Transportation Secretary Norman Y. Mineta @ http://www.dot.gov/affairs/nhtsa4601.htm
Tire Inflation Pressure Loss

- Tires lose inflation gases continuously, since rubber compounds are permeable to gas molecules (losses also exist through tire/wheel/valve interfaces).
- Tubeless tires require an innerliner compound with low permeability to limit the loss of inflation.
- The ASTM F1112-06 test measures the static loss of inflation gas from a tire over time.
  - Data is reported as % loss / month.
ASTM F1112-06 Inflation Pressure Loss Rate (IPLR)

- **Test Room**
  - Mean temperatures of 21, 24, 30 or 38°C (normal test is 21°C) ±0.6°C (±1°F)
  - Forcibly circulated air controlled at ±3°C (±5°F)

- **Gauges or Pressure Transducers**
  - Resolution 2 kPa (0.25 psi) accurate to ±1% of measured value (operating within 40 to 90% of full scale)

- **Data Acquisition**
  - Record data once per day for 180 days; or computer data acquisition of more data points per day for a shorter duration test

- **Barometer (High Accuracy)**
Tires are inflated to a specified pressure and sit static and unloaded in a controlled environment

- NHTSA testing used FMVSS No. 139 High Speed test pressures
- NHTSA testing was conducted at 21°C ± 3°C

The pressure and conditions are monitored over time

- NHTSA testing used 90 days with continuous monitoring of the pressure via computer interface
  - Per the ASTM standard the first 30 days data was discarded

Data is then corrected to a standard temperature and barometric pressure

- 21°C and 101.3 kPa
Rate stabilizes during initial 30 days.

30 - 90 day data is used to calculate Inflation Pressure Loss Rate (IPLR).
**Is there a difference in (IPLR) when varying $N_2/O_2$ ratio?**

**One-way ANOVA analysis of IPLR:**

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
<th>R-Square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>27</td>
<td>56.41</td>
<td>2.089</td>
<td>22.56</td>
<td>&lt;.0001</td>
<td>0.902</td>
</tr>
<tr>
<td>Error</td>
<td>66</td>
<td>6.11</td>
<td>0.092</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>93</td>
<td>62.52</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Type III SS</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inflation Gas</strong></td>
<td>1</td>
<td>6.842</td>
<td>6.842</td>
<td>73.90</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td><strong>Test Lab</strong></td>
<td>1</td>
<td>0.017</td>
<td>0.017</td>
<td>0.19</td>
<td>0.6668</td>
</tr>
<tr>
<td><strong>Tire Type</strong></td>
<td>25</td>
<td>40.53</td>
<td>1.621</td>
<td>17.51</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

Inflation Gas and Tire Type are Significant Variables
IPLR with Air vs. $N_2$ Inflation

17 Different Models of Tires

Average IPLR for $N_2$ was 66% of Air
Tire Parameters

- **Approximate innerliner variations:**
  - Polymer: 100% IIR \(\rightarrow\) 80/20 NR/SBR
  - Carbon black: 53 \(\rightarrow\) 76 phr
  - Non-black filler: 0 \(\rightarrow\) 22 phr
  - Total filler: 67 \(\rightarrow\) 105 phr
  - Volatiles: 13 \(\rightarrow\) 26 phr
  - Thickness: 0.67 \(\rightarrow\) 1.85 mm

- **Initial Inflation Pressure:** 220 \(\rightarrow\) 521 kPa
Of the variables studied, innerliner composition and minimum innerliner thickness in the crown had most significant effect on IPLR

- Filler and volatiles had significant, but lesser effects

Analysis of difference in IPLR between air and $N_2$ \( (\text{IPLR}_{\text{air}} - \text{IPLR}_{\text{nitrogen}}) \) by tire type

- No significant effect of any construction parameter
- No significant effect of initial inflation pressure
  - i.e. no difference for Passenger vs. LT tires

Benefits of Nitrogen Inflation on IPLR appear to be Applicable to All Tire Types
Oxygen Concentration Measurement Equipment

Balston ®
72-730
Oxygen Analyzer
Accurate to <0.1% O₂
O₂ Migration During Test

Change in Percent Oxygen Concentration During IPL Test Versus Starting Oxygen Concentration

\[ y = -0.0016x^2 - 0.0519x + 0.2166 \]

\[ R^2 = 0.9156 \]
Change in $O_2$ Levels

- Faster migration of $O_2$ changes mixture of gas during 90-day test
  - Tires inflated with air lost average of 1.5% $O_2$
  - Tires inflated with $N_2$ lost or gained $O_2$ to approach equilibrium partial pressure

- Validation of Laboratory Results with On-Vehicle Data
  - $O_2$ levels were measured for 76 tires that were in-service (19 vehicles) in Akron, OH
  - Tires were originally inflated with shop air at various locations, no special procedures
No Correlation Between Inflation Pressure and % $O_2$

During service with top-offs of normal air, the oxygen permeates out at a faster rate than the nitrogen. This can result in a >50% reduction in net oxygen levels in the tire inflation gas during normal service.
**O$_2$ Level Significantly Reduced In-Service**

<table>
<thead>
<tr>
<th>Oxygen Range (% of inflation gas)</th>
<th>Number of Tires</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 → 11</td>
<td>4</td>
</tr>
<tr>
<td>11.1 → 13</td>
<td>18</td>
</tr>
<tr>
<td>13.1 → 15</td>
<td>18</td>
</tr>
<tr>
<td>15.1 → 17</td>
<td>17</td>
</tr>
<tr>
<td>17.1 → 19</td>
<td>14</td>
</tr>
<tr>
<td>19.1 → 20.0</td>
<td>5</td>
</tr>
<tr>
<td><strong>15.02 Average</strong></td>
<td></td>
</tr>
<tr>
<td><strong>2.79 Standard Deviation</strong></td>
<td></td>
</tr>
</tbody>
</table>

Indicates Reduced Potential Benefits for N$_2$ Inflation in Normal Tire Service
Theoretical Distribution of IPLR Normalized to Air Rate = 100 for Tire Type. Normalized Distribution of:

_____ Air with 20.9% O2 _____

-------------- Nitrogen ---------------

__- Air, Depleted of O2 in Service __-

IPLR\_avg = 1.4

IPLR\_avg = 2.1

IPLR\_avg = 1.8
Inflation Pressure Loss During Roadwheel Testing Was 37% Less for Tires Inflated with N₂ vs. Tires Inflated with Air
Change in %O₂ During Dynamic Loaded Operation

Higher %O₂ Gas Diffuses More Rapidly During Dynamic Roadwheel Testing
Does $N_2$ Have a Direct Effect on Rolling Resistance?

- 24 Tires were compared for Rolling Resistance, either inflated with $N_2$ or Air
  - SAE J1269 Single-Point Test
- **Average Rolling Resistance**
  - Air = 12.80 pounds ±0.38
  - $N_2$ = 12.65 pounds ±0.44

- No Direct Effect Observed for $N_2$ Inflation on Tire Rolling Resistance
- The Only Significant Effect on Tire Rolling Resistance may be **Indirect**:
  - Due to Better Retention of Inflation Pressure over Time
Effects on Tire Durability

The benefits of N₂ inflation on oven-aged tires has been shown*

The tires were filled with 50/50 N₂/O₂, air or N₂ and oven-aged for 5 weeks @ 65°C

They were then tested according to the FMVSS 139 Endurance and Low Pressure Test (to failure or 35.5 hours stop-finish)

50/50 N₂/O₂ had a significant deleterious effect. Tires aged with N₂ or air inflation all passed test @ 35.5 hrs

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In laboratory testing, tires inflated with 94-99% N₂ showed a 34% reduction in pressure loss versus tires inflated with air (78% N₂)

- Based on reduced O₂ observed for in-service tires, the benefits of N₂ in service would be significantly reduced
- Tires inflated with N₂ above 97% purity showed diffusion of O₂ into the tire at 90 days

Similar reduction in IPLR for tires inflated with N₂ during 700-hour dynamic, loaded roadwheel test

Innerliner composition and initial inflation pressure had no significant effect on reduction of IPLR for N₂ versus air
Tire inflation with N\textsubscript{2} versus air had no significant effect on rolling resistance
  - Benefits of N\textsubscript{2} will likely be indirect from improved retention of inflation pressure over time

Laboratory tire endurance after oven aging was reduced by high O\textsubscript{2} content in inflation gas during oven aging
  - Tires inflated with air or N\textsubscript{2} during aging completed the post-oven 35.5 hour test with no failures
  - Previous studies have shown benefits for tire roadwheel endurance when tires inflated with N\textsubscript{2} during aging