EVALUATION OF NITROGEN INFLATION OF TIRES

presented to

Beijing University of Chemical Technology
Beijing, China
Background: Reported Benefits of Nitrogen

One example of reported claims for inflating tires with nitrogen gas:

- **Constant pressure**: “Nitrogen molecules are four times larger than air and as a result will not seep through the casing of the tyre like air, which would normally result in pressure loss. Nitrogen is also a more stable gas than air and as such will not give high fluctuations in temperature and therefore pressure within the tyre”.

- **No oxidation**: “As normal compressed air passes through the casing of the tyre, oxidation is caused within the tyre belts, reducing the life of the casing and increasing the risk of blow outs. As nitrogen is clean and dry, there is no moisture and the larger nitrogen molecules will not pass through the tyre casing like air”.

- **Lower running temperature**: “Fluctuation in pressure means increased temperature resulting in increased tyre wear. As the pressure in the tyre is more constant, you will not get the increase in temperature and pressure like you get with tyres inflated with normal compressed air”.

- **3 per cent saving on fuel costs**: “As the tyre loses pressure, the tyre surface on the road increases. With a 10 per cent reduction in tyre pressure, research has shown that you will get a 3 per cent increase in fuel usage”.

Ref: Bowen Independent (Australia), March 7, 2007, Pg. 17
Key Points

• Constant Pressure $\rightarrow$ Inflation Pressure Loss Rate
• No Oxidation $\rightarrow$ Age Resistance
• Reduced Risk of Blow Outs $\rightarrow$ Durability/Endurance
• Lower Running Temperature $\rightarrow$ Rolling Resistance
• Savings on Fuel Costs $\rightarrow$ Vehicle Fuel Economy
Agenda

• Constant Pressure
  – Gas Diffusion in Rubber
  – Experimental Tires
  – ASTM F11112 Test
  – Literature Results

• Oxidation
• Roadwheel Durability
• Rolling Resistance
• Vehicle Fuel Economy
• Summary
Constant Pressure: Gas Diffusion in Rubber

- **Nitrogen** (0.10977nm) molecule is similar size to oxygen (0.12074nm)  

- **Nitrogen is 50% less soluble in natural rubber than is oxygen gas**  
  (Ref: van Amerongen, “Diffusion in Elastomers”, Rubber Reviews, 37, 1065 (1964))

- **Nitrogen gas calculated to be 30% - 40% less permeable in rubber than is oxygen gas**
  
  - Natural Rubber @25°C  
    - N₂ = 6.12  
    - O₂ = 17.7 \((10^{-8}\text{cm}^2.\text{sec}^{-1}.\text{atm}^{-1})\)  
    - For Natural Rubber \(Q_{\text{Air}} \sim 1.4\ Q_{\text{Nitrogen}}\) \(\Rightarrow \) 70% of Air Value

  - Butyl Rubber @25°C  
    - N₂ = 0.247  
    - O₂ = 0.99  
    - For Butyl Rubber \(Q_{\text{Air}} \sim 1.63\ Q_{\text{Nitrogen}}\) \(\Rightarrow \) 60% of Air Value

**Nitrogen Less Soluble \(\Rightarrow\) Less Permeable than Oxygen**
Constant Pressure: Production of Expt Tires

- Compounds prepared in 2-step factory mix
  - GK400 sheeted out on extruder with roller die
  - GK160 sheeted out on two-roll mill
- Experimental summer tires made on full automatic building machines
  - 205/60 HR15
  - 205/60 SR15 (no nylon cap ply)
  - Cured innerliner gauges of 1.0 mm

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
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<tbody>
<tr>
<td>Exxon™ Bromobutyl 2222</td>
<td>100</td>
<td>80</td>
<td>60</td>
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<tr>
<td>Natural Rubber, SMR 20</td>
<td></td>
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<tr>
<td>Processing Aid, 40MS</td>
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<td>7</td>
<td>7</td>
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<tr>
<td>Carbon Black, N660</td>
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<td>60</td>
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<tr>
<td>Processing Aid, SP1068</td>
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<tr>
<td>Processing Oil, TDAE</td>
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<tr>
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<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Zinc Oxide</td>
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<td>1</td>
<td>1</td>
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<tr>
<td>Sulfur</td>
<td>0.5</td>
<td>0.5</td>
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<tr>
<td>Accelerator, MBTS</td>
<td>1.25</td>
<td>1.25</td>
<td>1.25</td>
</tr>
</tbody>
</table>
Constant Pressure: Inflation Pressure Loss Rate

- ASTM F-1112 (modified)
  - Use of sensitive pressure transducers with computer allows significant shortening of test
  - Two weeks equilibration at 21°C before starting the 4-week test
  - Tire start pressure = 2.2 bar (220 kPa or 32 psi)
  - Computer automatically records measurement every second
  - Test duration as short as 42 days
Constant Pressure: Fill Gas Effects on IPLR

Used ASTM F-1112 (modified) to study Inflation Pressure Loss Rates of 205/60 SR15 tires built with different innerliners

- Tires purged 3X in order to obtain pure fill gas: dry 99.4% nitrogen

**Tire IPLR Reduced 40% Using Dry, Pure Nitrogen Gas Inflation**
Constant Pressure: Fill Gas Effects - Literature

**Consumer Reports**

- **Studied 31 H- and V-rated, all-season tires**
  - Filled with nitrogen / deflated 3X to purge air out of tire
  - Oxygen analyzer used to ensure 95% nitrogen purity
  - One-year test showed nitrogen reduces pressure loss over time.
  
  From initial 30 psi, 3.5 psi air pressure loss, while nitrogen-filled tires lost average of 2.2 psi: **37% lower for tires inflated with nitrogen gas**

**National Highway Traffic Safety Administration (NHTSA)**
(Ref: MacIsaac, Evans, Harris, Terrill, "The Effects of Inflation Gas on Tire Laboratory Performance", ITEC 2008, 9/16-18/08)

- **Studied nitrogen (94 to 99%) inflation of 25 passenger or LT tires**
  - **34% lower IPLR for tires inflated with nitrogen gas**
  - Tire type also a statistically significant variable

**In agreement with claims:**

**Tire IPLR Reduced ~35% Using Nitrogen Inflation**
Agenda

• Constant Pressure

• Oxidation
  – Oven Aging od Tires
  – Component Testing of Aged Tires

• Roadwheel Durability

• Rolling Resistance

• Vehicle Fuel Economy

• Summary
Oxidation: Tire Oven Aging Study

205/60 SR15 tires aged in air-circulating oven: 4 weeks @ 70°C
• 100-phr Bromobutyl rubber, and 80/20 and 60/40 BIIR / NR liners
• Tires inflated with dry nitrogen (99.9%), dry air, or 50/50 O₂ / N₂ mixture

Oven-aged tires tested on a 1.7-m laboratory roadwheel according to the NHTSA Federal Motor Vehicle Safety Standards
• FMVSS 139 Endurance / Stepped-Up Load to failure

New and oven-aged / road wheel tested tires cut and analyzed by contract lab: Akron Rubber Development Laboratory
• Tensile Properties: 100% Modulus, Elongation at Break
• Crosslink Density
• Fixed Oxygen
• Peel Strength
• Laser Shearography
Oxidation: Fill Gas Effects on Tensile Properties

Tensile Changes of Oven-Aged Tires:

*Increases with Increasing Oxygen*
Oxidation: Fill Gas Effects on Crosslink Density

Crosslink Changes of Oven-Aged Tires: 
*Increases with Increasing Oxygen*

% - Change due to oxidative aging can be calculated
- Air: 20%
- O₂/N₂ (50/50): 40%
**Oxidation: Fill Gas Effects on Fixed Oxygen**

Fixed Oxygen is covalently bonded oxygen content measured for natural rubber wire coat and shoulder wedge compounds:
- Leco CHNS-932 uses elemental analysis technique to determine %-Oxygen by weight denoting covalently bound Oxygen in sample.
- Pyrolyze mg sample in tin cup in high-carbon environment at 1050°C to form CO, then convert to CO₂, and detect via its infrared absorption.

**Fixed Oxygen Changes of Oven-Aged Tires:**

*Increases with Increasing Oxygen*
Oxidation: Fill Gas Effects on Belt Peel Strength

Peel Strength conducted per ASTM D 413 Type A, 180° peel

Peel Strength Changes of Oven-Aged Tires: *Increases with Increasing Oxygen*

ExxonMobil Chemical Company Analysis
Relating Shearography to Tire Defects

Progression of belt edge defects along the two belt edges
Example Optical Micrograph of Aged / Tested Tires

1x1-inch region of 205/60 SR15 passenger tire with Bromobutyl / NR (80/20) innerliner, Tire IPLR = 2.0

Visible Damage: 35.5 hrs
Oxidation: Fill Gas Effects on Shearography Cracks

Shearography

Cracks, mm²

<table>
<thead>
<tr>
<th>Compound</th>
<th>Air Inflated</th>
<th>Nitrogen Inflated</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 BIIR</td>
<td>642</td>
<td>0</td>
</tr>
<tr>
<td>80/20 BIIR/NR</td>
<td>12,729</td>
<td>0</td>
</tr>
<tr>
<td>60/40 BIIR/NR</td>
<td>25,344</td>
<td>500</td>
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</table>

Cracking of Aged Tires Significantly Reduced by Reducing Oxygen

ExxonMobil Chemical Company Data
Shearography Cracking Quantitatively Correlates to Tire Inflation Pressure Loss Rates
Agenda

- Constant Pressure
- Oxidation
- **Roadwheel Durability**
  - FMVSS 139 Endurance of New Tires
  - FMVSS 139 Endurance / SUL of Aged Tires
- Rolling Resistance
- Vehicle Fuel Economy
- Summary
Roadwheel Durability: Impact of IPLR on FMVSS 109

205/60 SR15 tires made compositions tested to FMVSS 109 Endurance standards (80 km/h), but running until the tire fails

**Modified FMVSS 109 Endurance: S-Rated Tires**

<table>
<thead>
<tr>
<th>Inflation Pressure Loss Rates, %-loss/month</th>
<th>Hours to Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.45</td>
<td>319.6</td>
</tr>
<tr>
<td>2.00</td>
<td>273.9</td>
</tr>
<tr>
<td>2.65</td>
<td>171.4</td>
</tr>
</tbody>
</table>

$R^2 = 0.9533$

Excellent Correlation of Hours to Failure to Tire IPLR
Roadwheel Durability: Impact of IPLR on FMVSS 139

205/60 HR15 tires made with different innerliner compositions tested to FMVSS 139 Endurance standards (120 km/h), running until tire fails

Good Correlation of Hours to Failure to Tire IPLR
Roadwheel Durability: Fill Gas Effects on Endurance

**FMVSS 139 Endurance test modified by**
- Running at final test conditions until the tire fails
- Using dry 99.9% nitrogen as the fill gas \( \Rightarrow \) 99.4%

**No Effect of Nitrogen on Lab Roadwheel Testing:**

*Performance of New Tires Comparable*
Roadwheel Durability: Impact of IPLR on FMVSS 139

FMVSS 139 Endurance test modified by following-up with a Stepped-Up Load test until failure
• Temperature: 38°C, Speed: 120 km/h, Pressure: 180 kPa dry air
• Load: 4 hr @85% / 6 hr @90% / 24 hr @100% of rating
• Stepped-Up Load: increase 10% @ 4-hr intervals until the tire fails

Roadwheel Performance of New Tires Comparable

ExxonMobil Chemical Company Data
Roadwheel Durability: Fill Gas Effects on Endurance

Roadwheel Endurance of Aged Tires Improved

**using Dry 99.4% Nitrogen Gas Inflation**
Roadwheel Durability: Fill Gas Effects on Endurance

Roadwheel Endurance Quantitatively Correlates to Tire Inflation Pressure Loss Rates
Agenda

- Constant Pressure
- Oxidation
- Roadwheel Durability
- **Rolling Resistance**
  - SAE J1269, SAE 2452
  - Temperature
  - Coefficient
- Vehicle Fuel Economy
- Summary
Rolling Resistance: Characterization Tests

- Rolling resistance measured at Smithers Rapra on 1.7-meter indoor roadwheel at 24°C
  - 205/60 SR15, 100-phr BIIR innerliner with cured gauge of 1.0 mm
  - Six inflation pressures requested: 32, 31, 30, 28, 26, 24 psi

- Single Point Inflation
  - Measured at 50 mph, 70% load and one inflation pressure
    - Repeated six times: 32, 31, 30, 28, 26, and 24 psi hot inflation
  - Tire Footprints obtained and areas determined

- SAE J1269
  - Current recommended practice used to evaluate tires by tire industry
  - Measured at constant 50 mph speed at 50% and 90% of maximum load and two inflation pressures

- SAE J2452
  - Current recommended practice used to evaluate tires and effect on vehicle fuel economy
    - Many vehicle manufacturers use this technique to generate CAFE predictions
  - Measured at speed of 71 mph coasting down to 9 mph at two loads and two inflation pressures
    - Rolling resistance values calculated from regression curve
Rolling Resistance: Comparison of Tests

- **Three tests run:** Single-point inflation, SAE J1269 and SAE J2452
  - Tests on experimental tires: 205/60 SR15

  ![Test Methods Comparison](image)

- **Rolling resistance (RR) measured experimentally**
  - Excellent reproducibility between methods: Mean = 10.754, SD = 0.045
• Three tests run: Single-point inflation, SAE J1269 and SAE J2452
  – Tests on experimental tires: 205/60 SR15

• Rolling resistance (RR) measured experimentally
  – Excellent reproducibility between tires: Mean = 10.754, SD = 0.20
Rolling Resistance: Effect of Tread Footprint

With 25% Pressure Loss, Footprint Area Increases 20%
Rolling Resistance: Fill Gas Effects on Temperature

Cavity Gas Temperature

- Air
- Linear (Air)

$R^2 = 0.9708$

Cavity Air Temperature Dependent Upon Inflation Pressure
Rolling Resistance: Fill Gas Effects on Temperature

Cavity Air Temperature Does Not Change using Nitrogen Gas

Cavity Gas Temperature

- Air
- Nitrogen

R² = 0.9708
R² = 0.9782

Degrees C

Inflation Pressure, kPa

Cavity Air Temperature Does Not Change using Nitrogen Gas
Rolling Resistance: Fill Gas Effects on Coefficient

Tire Rolling Resistance Dependent Upon Inflation Pressure

Rolling Resistance Coefficient

- Air
- Linear (Air)

R² = 0.9716
Rolling Resistance: Fill Gas Effects on Coefficient

Tire Rolling Resistance Does Not Change Using Nitrogen
Rolling Resistance: Fill Gas Effects from Literature

National Highway Traffic Safety Administration
(Ref: MacIsaac, Evans, Harris, and Terrill, “The Effects of Inflation Gas on Tire Laboratory Performance”, ITEC 2008, 9/16-18/08)

• Studied rolling resistance of 24 tire types and ASTM F2493-06 SRT

• SAE J1269 test procedure

• Filling with nitrogen gas or air inflation gave essentially identical results

\[ RR_{\text{Air}} = 12.80\pm0.38 \text{ lbs} \]
\[ RR_{\text{N2}} = 12.65\pm0.44 \text{ lbs} \]

In Agreement with NHTSA Results:

*Tire Rolling Resistance Equivalent Using Nitrogen Gas*
Agenda

- Constant Pressure
- Oxidation
- Roadwheel Durability
- Rolling Resistance
- **Vehicle Fuel Economy**
- Summary
Vehicle Fuel Economy: In-Service Equipment

New tires were tested on four vehicles driven under normal city driving conditions using dry air or dry 99+% nitrogen gas inflation from purchased cylinders

• Tires were purged and refilled three times in order to obtain pure dry nitrogen gas inflation (99+%)
Vehicle Fuel Economy: Tire Pressure Loss Rates

Tire Inflation Pressure Loss Rates (%-month) dependent upon tire type and measurement type

- ASTM F1112 measured at 21°C for unloaded, static tire
- In-service IPLR measured at ambient temperatures for tires on vehicles

In-Service Loss Rates Increased Significantly: 50 – 125%
Inflation pressure was measured directly for each tire on the vehicle, and the average value for all four tires was used to calculate tire IPLR monthly loss rates based on 10 weeks of data
• Inflation cycle: Air, Nitrogen, Air, and Nitrogen

Loss Rates are Reduced Using Nitrogen to Inflate Tires
Vehicle Fuel Economy: In-Service Miles Driven

Vehicle miles driven under normal city/highway conditions

- Gallons of gas consumed recorded for each fill-up during the four 10-week time periods: 45,961 total miles driven

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Miles Driven</th>
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<tbody>
<tr>
<td></td>
<td>Air</td>
</tr>
<tr>
<td>1</td>
<td>4030</td>
</tr>
<tr>
<td>2</td>
<td>2726</td>
</tr>
<tr>
<td>3</td>
<td>2328</td>
</tr>
<tr>
<td>4</td>
<td>3449</td>
</tr>
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</table>

Vehicle Miles Driven

ExxonMobil Chemical Company Data
Average miles per gallon was obtained under normal city driving conditions in order to determine the effect of nitrogen inflation on vehicle fuel economy.

ExxonMobil Chemical Company Data
Vehicle Fuel Economy: Miles per Gallon of Gasoline

Average miles per gallon was obtained in order to determine the effect of nitrogen inflation on vehicle fuel economy.

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Air</th>
<th>N2</th>
<th>Air-2</th>
<th>N2-2</th>
<th>Average</th>
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<tbody>
<tr>
<td>1</td>
<td>20.1</td>
<td>20.3</td>
<td>19.9</td>
<td>19.6</td>
<td>20.0</td>
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<tr>
<td>2</td>
<td>23.1</td>
<td>22.2</td>
<td>22.2</td>
<td>23.7</td>
<td>22.8</td>
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<tr>
<td>3</td>
<td>21.7</td>
<td>22.2</td>
<td>22.8</td>
<td>23.0</td>
<td>22.4</td>
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<tr>
<td>4</td>
<td>28.5</td>
<td>28.1</td>
<td>28.9</td>
<td>28.5</td>
<td>28.5</td>
</tr>
</tbody>
</table>

Vehicle Fuel Economy

![Bar chart showing vehicle fuel economy for different nitrogen types and vehicles.](chart.png)
### Scaled Estimates

Nominal factors expanded to all levels
Continuous factors centered by mean, scaled by range/2

| Term     | Scaled Estimate | Std Error | t Ratio | Prob>|t| |
|----------|-----------------|-----------|---------|--------|
| Intercept| 23.476592       | 0.117268  | 200.20  | <.0001*|
| Vehicle[1] | -3.563654     | 0.30291   | -11.76  | <.0001*|
| Vehicle[2] | -0.723551     | 0.204661  | -3.54   | 0.0005*|
| Vehicle[3] | -1.108091     | 0.282286  | -3.93   | 0.0001*|
| Vehicle[4] | 5.3952963    | 0.195129  | 27.65   | <.0001*|
| GAS[A]   | -0.163009      | 0.270548  | -0.60   | 0.5478 |
| GAS[N]   | 0.1630093      | 0.270548  | 0.60    | 0.5478 |
| Test[1]  | -0.071843      | 0.106705  | -0.67   | 0.5018 |
| Test[2]  | 0.071843       | 0.106705  | 0.67    | 0.5018 |
| IPR      | 0.0844243      | 0.452126  | 0.19    | 0.8521 |
| TEMP     | 0.0303879      | 0.258682  | 0.12    | 0.9066 |
| BAROMETER| -0.169403      | 0.321029  | -0.53   | 0.5985 |
| Tire KPa | -0.191698      | 0.381145  | -0.50   | 0.6157 |

**Vehicle Type is Only Statistically Significant Variable, Prob>|t|<0.1**

### Prediction Profiler

**Inflation Gas Not Statistically Significant: Prob>|t|=0.9**
Vehicle Fuel Economy: Effects of Different Vehicles

Vehicle 1

No Statistical Difference Using Air or Nitrogen to Fill Tires

ExxonMobil Chemical Company Data
Vehicle Fuel Economy: Effects of Different Vehicles

Vehicle 2

No Statistical Difference Using Air or Nitrogen to Fill Tires
Vehicle Fuel Economy: Effects of Different Vehicles

Vehicle 3

No Statistical Difference Using Air or Nitrogen to Fill Tires
Vehicle Fuel Economy: Effects of Different Vehicles

Vehicle 4

No Statistical Difference Using Air or Nitrogen to Fill Tires
Vehicle Fuel Economy: Pressure Effects on Gas Mileage

**Scaled Estimates**

Nominal factors expanded to all levels
Continuous factors centered by mean, scaled by range/2

| Term       | Scaled Estimate | Std Error | t Ratio | Prob>|t| |
|------------|-----------------|-----------|---------|-----|
| Intercept  | 23.272876       | 0.264082  | 88.13   | <.0001 |
| GAS[A]     | -0.719682       | 0.559837  | -1.29   | 0.2006 |
| GAS[N]     | 0.719682        | 0.559837  | 1.29    | 0.2006 |
| Test[1]    | 0.268535        | 0.261499  | 1.03    | 0.3061 |
| Test[2]    | -0.268535       | 0.261499  | -1.03   | 0.3061 |
| IPR        | 2.309092        | 0.760493  | 3.04    | 0.0028 |
| TEMP       | -0.712766       | 0.582897  | -1.22   | 0.2233 |
| BAROMETER  | 0.904090        | 0.784105  | 1.15    | 0.2507 |
| Tire KPa   | 2.8965044       | 0.733452  | 3.95    | 0.0001 |

**Prediction Profiler**

**Tire Inflation Pressure and Tire IPLR are Statistically Next Most Important Variables**
Vehicle Fuel Economy: Effects of Air vs. N₂ Inflation

ExxonMobil Chemical Company Data

No Statistically Significant Difference in Vehicle Fuel Economy Using Air or Nitrogen
Vehicle Fuel Economy: Effects of Air vs. N\textsubscript{2} Inflation

No Statistically Significant Difference:
Using Means gives +2.7%, Using Averages gives -2.3%

<table>
<thead>
<tr>
<th>Level</th>
<th>Number</th>
<th>Mean</th>
<th>Std Error</th>
<th>Lower 95%</th>
<th>Upper 95%</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>70</td>
<td>23.0244</td>
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<td>N</td>
<td>87</td>
<td>23.6474</td>
<td>0.38912</td>
<td>22.879</td>
<td>24.416</td>
</tr>
</tbody>
</table>

Each Pair
Student's t
0.05

Avg Air = 23.66
Avg N\textsubscript{2} = 23.13
-2.3%
Vehicle Fuel Economy: Temperature Effects - N₂

Temperature Effect of Using Air Conditioner in Summer Months during Nitrogen-1 Measurements

<table>
<thead>
<tr>
<th>Level</th>
<th>Number</th>
<th>Mean</th>
<th>Std Error</th>
<th>Lower 95%</th>
<th>Upper 95%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>42</td>
<td>23.3186</td>
<td>0.58545</td>
<td>22.155</td>
<td>24.483</td>
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<td>2</td>
<td>45</td>
<td>23.9542</td>
<td>0.56560</td>
<td>22.830</td>
<td>25.079</td>
</tr>
</tbody>
</table>

Std Error uses a pooled estimate of error variance

2.7% Difference
Vehicle Fuel Economy: Temperature Effects - Air

Temperature Effect of Using Air Conditioner in Summer Months during Air-2 Measurements

11.1% Decrease

ExxonMobil Chemical Company Data
Summary

Use of dry 99.4% nitrogen as the fill gas

- **Reduces oxidation of the natural rubber wire coat compound**
  - Linear decrease in peel strength of skim with increasing oxygen in the fill gas during laboratory oven aging
- **Reduces tire IPLR by 40%**
- **Does not have primary affect on Cavity Gas Temperature**
  - Cavity gas temperature dependent upon tire pressure: IPLR
- **Does not have primary affect on Tire Rolling Resistance**
  - Rolling resistance dependent upon tire inflation pressure: IPLR

*Reducing Tire IPLR and Reducing Oxidation are the Primary Effects of Using Nitrogen Gas Inflation*
Summary

- Tire IPLR measured in-service is much greater than when measured using ASTM F1112 test protocol at room temperature
  - 50 - 125% increase in monthly loss rates
  - Use of dry 99+% nitrogen to inflate tires for in-service testing on vehicles shows 50% lower tire IPLR

- Tire type is only statistically significant variable using Prob>|t|<0.1
  - Inflation gas type is not statistically significant: Prob>|t|=0.9

- No statistical difference in fuel economy using air or nitrogen to inflate tires during 46,000-mile in-service 4-vehicle study

- Effect of ambient temperature observed on vehicle fuel economy since measured mpg lowest in summer months
  - Up to 11% decrease in vehicle mpg when air-conditioning is turned on during summer months
Evaluation of Nitrogen Inflation of Tires

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