The TOV Viscometer System
In-Line Viscosity Measurement

History of Mansco Products:
- Founded in the 1960’s.
- Located in Ivyland, Pennsylvania, USA
- Over 35 years of Viscosity Measurement Experience

History of TOV:
- TOV System was co-developed between Mansco Products and DuPont over 35 years ago
- Secrecy agreements ended in 1998 enabling a new agreement for Mansco to market and install TOV’s worldwide
- The TOV has been used for DuPont technology since its inception….and continues today.
- Hundreds of installations into various products and applications worldwide
- TOV has over 35 years of field experience
The TOV Viscometer System
In-Line Viscosity Measurement

TOV System Worldwide distribution
The general rule is: “If the fluid can be pumped, then it can be measured using the TOV Viscometer System. Applications of the TOV Viscometer System include:

Examples of Cp Applications
- Polyester
- Nylon
- Acrylic
- Polyethylene
- Polyurethane
- Polypropylene
- Polycarbonate
- Polysulfone
- Spandex

Examples of Batch Applications
- Polyester
- Nylon
- Spandex

Examples of Extruder Applications
- Polyester
- Films
The TOV Viscometer System
In-Line Viscosity Measurement

Model TOVS Probe

TOVS Probe's Construction
All weld construction allows TOVS Probe to be designed for high pressures (over 10,000 PSI or 700 Kg/cm²) and high temperatures (up to 350°C).

The Probe's Sensor
Viscosity sensor is sized and shaped according to the specifications for greater sensitivity.

Mass Flange
The massive flange provides reference inertia to reduce and eliminate extraneous plant noise influences.

Platinum RTD Element
The built-in Platinum RTD provide a very accurate temperature reading (.1% accuracy) at the point where temperature is most significant... where viscosity is measured.

The Probe's interior and torsional system
Operates utilizing the torsional principal. This means no motors, less moving parts, and virtually no maintenance.

Model TOVS Probe is typically installed into pipelines and/or extruder ends.

Contact Info
Model TOVL Probe is typically installed into vessels directly or at the end of an extruder.

**The Probe’s Sensor**
Viscosity sensor is sized and shaped according to the specifications for greater sensitivity.

**Flange**
The TOVL flange is smaller than the TOVS flange. TOVL Probes are installed into large vessels that already have high inertia to dampen noise when compared to a pipeline.

**TOV Probe’s Construction**
All weld construction allows TOVL Probe to be designed for high pressures (over 10,000 PSI or 700 Kg/cm²) and high temperatures (up to 350°C).

**Platinum RTD Element**
The built-in Platinum RTD provide a very accurate temperature reading (.1% accuracy) at the point where temperature is most significant... where viscosity is measured.

**The Probe’s interior and torsional system**
Operates utilizing the torsional principal. This means no motors, less moving parts, and virtually no maintenance.
The TOV Viscometer System
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How it works . . .

- The TOV Probe’s sensing device is immersed in process fluid.
- The TOV Probe is allowed to oscillate at its own resonance frequency…no motors or gears.
- Power to start and maintain the TOV Probe’s oscillation is supplied by the TOV Transducer.
- As the fluid viscosity increases, more power is needed to maintain the oscillation. For a lower viscosity, less power is needed.
- The Transducer continually monitors how much power is needed to maintain the oscillation meaning that the viscosity is constantly being monitored. It is an analog feedback loop meaning no sampling time….only REAL TIME measurement.
The TOV Viscometer System
In-Line Viscosity Measurement

Located in the control room by the Digital Control System. There are 2 general models available, TOVM and TOVL.

### Features and Specs

<table>
<thead>
<tr>
<th>Feature</th>
<th>TOVM 1.4</th>
<th>TOVL 1.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Input from Field: 110VAC 50/60Hz Service</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Maximum Power Output: 0.5 Amps from P.S.</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Pressure Compensation: Max Press Comp: Span of Incoming Pressure Transmitter</td>
<td>✓</td>
<td>Optional</td>
</tr>
<tr>
<td>Linear Temperature Compensation from Probe RTD signal within +/- 14°C (57.2°F) from setpoint</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Multi-Features</td>
<td>✓</td>
<td>Not Available</td>
</tr>
<tr>
<td>In-line Probe Performance Tests for testing Probe operating parameters:</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Built-in Simulator feature</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>LED Readout of Direct Process Temperature</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Built-in Differential Voltage Meter</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Start-up Power Checks</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Microprocessor features</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Noise reduction conditioning</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

### Model SC-03 Slide Chassis

New Features
- Built-in Differential Meter
- Automatic Start-up Power Supply Checks
- Manual Power Supply Checks
- New LCD Display
The TOV Viscometer System
In-Line Viscosity Measurement

Transducers provide outputs for use in the DCS for charting and control.

**Transducer Outputs**

<table>
<thead>
<tr>
<th>Transducer Model</th>
<th>TOVM 1.4</th>
<th>TOVL 1.1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Analog Output Signals (4-20 mA)</strong></td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td><strong>Compensated Viscosity</strong></td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Compensated for temperature and pressure so that only REAL viscosity changes are measured.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Uncompensated Viscosity</strong></td>
<td>√</td>
<td>Not Available</td>
</tr>
<tr>
<td>The &quot;raw&quot; viscosity signal from the TOV Probe.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Broad Temperature Output Ranges Available:</strong></td>
<td>√</td>
<td>Not Available</td>
</tr>
<tr>
<td>- 0 to 100°C (32 to 212°F)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- 100 to 200°C (212 to 392°F)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- 200 to 300°C (392 to 572°F)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- 250 to 350°C (482 to 662°F)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- 0 to 350°C (32 to 662°F)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Compensating Temperature:</strong></td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>+/-5°C (9°F) from Temperature Compensation setpoint</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The Adaptor is designed for the TOV Probe for a smooth interior to minimize any flow disruptions, pressure drops or process build-up.

The Adaptor and Probe can be designed for pipeline elbows (shown), pipeline straight-line “Tee”, vessel, or other configurations.

**Flow Splitter**
Designed to protect the Probe’s sensor from solid materials in the event of a “cold” process start-up without disrupting the process flow.

**Materials Match**
The materials of construction are made to match the Probe in order to match the thermal coefficients of expansion.

**Any Core Pipe Size or Schedule**
Adaptors are not limited by pipe sizes.

**Welds are Tested**
All core welds are x-rayed per ANSI 31.3 and the jacket welds are ultrasonically inspected per B31.3 criteria ASME Section 5 of the unfired pressure vessel code.
The TOV Viscometer System Installed into an “Elbow” Adaptor

- **TOV Probe**
- **Weld**
- **Smooth contoured surface**
  - For minimum flow disruption or build-up
- **Flow Splitter**
  - To prevent large solids from reaching the Probe sensor while not disturbing the flow.
- **Parabolic Flow**
- **Flange-to-Flange Mounting**
- **Flexitallic Gasket**
  - Provides tight seal
- **Even (“Plug”) Flow for accurate measurement**
- **Recommended Static Mixer**
- **Optional Direction of flow**

Recommended Direction of flow
The TOV Viscometer System
In-Line Viscosity Measurement

TOV Straight-Line Installation

The TOV Viscometer System
Installed into a “Tee” Adaptor
(straight section of pipe)

TOV Probe

Flexitallic Gasket
Provides tight seal

Weld

Smooth contoured surface
For minimum flow disruption and build-up

Flow Splitter
To prevent large solids from reaching the Probe sensor while not disturbing the flow.

Even (“Plug”) Flow for accurate measurement

Recommended Static Mixer

Revised Flow

Parabolic Flow
The TOV Viscometer System
In-Line Viscosity Measurement

The Probe and Adaptor

Pictures:
Top Left: The TOV Viscometer Probe is installed into the TOV Viscometer Adaptor.
Middle Left: A different view of the Probe as it is being installed into the Adaptor.
Above: The Probe installed into the Adaptor.
The TOV Viscometer System
In-Line Viscosity Measurement

Why the TOV Viscometer System?

The Control Feedback Loop: Polyester Example

How it works:
1. Probe is installed into the process pipeline.
2. Viscosity signal is sent to the Transducer.
3. Transducer sends compensated viscosity signal to DCS.
4. DCS sends controlling signal to vacuum controller.
5. Vacuum controller sends signal to the finisher vacuum. The Vacuum controller itself may be a part of the DCS or an external controller.
6. Feedback Loop is set so that 1% change in TOV viscosity measurement equals 1% change in vacuum control. This enables an automatic feedback control of the vacuum to control the viscosity.

The TOV is best used to control the viscosity of the polymer immediately after the finisher.

At this point the final viscosity can be controlled in a tight range in real time utilizing the in-line viscosity measurement of the TOV System.
The TOV Viscometer System
In-Line Viscosity Measurement

TOVL Vessel Installation

- Probe Protective Cage
- Flange Welded Into Vessel
- Gasket
- Alignment Rods
- TOV-L Probe
The TOV Viscometer System
In-Line Viscosity Measurement

1. The TOV can be used to measure the viscosity in the vessel itself to determine when the target viscosity is reached and the batch can be released from the vessel.

2. If many batches are combined, the resulting viscosity can be measured and controlled.

The TOV in-line Viscometer system can be used to control the viscosity in Batch applications.
The TOV Viscometer System
In-Line Viscosity Measurement

The TOV in-line Viscometer system can be used to control the viscosity in Extruder applications

1. The TOV can control the residence time of the flake or chip in the Heater to control the moisture and viscosity.

2. If present, the TOV can control the vacuum on the extruder much like on the finisher in CP applications to control the viscosity.
The TOV Viscometer System™

In-Line Viscosity measurement for better process control.

- In-line, real-time results….no lag times
- Superior to other viscosity measurement/control methods
  - Less lag time, greater reliability, less expense than lab samples
  - Less lag time, real time control, less maintenance expense, and more reliable sensitivity compared to capillary bypass systems
  - More reliable and sensitive results than other in-line models with no extra cooling and less noise influence.
- The market “L*E*A*D*E*R”

Low-maintenance  Effective  Accurate  Durable  Efficient  Reliable
The TOV Viscometer System
In-Line Viscosity Measurement

Why the TOV Viscometer System?

Melt Viscosity vs. Shear Rate

Non-Newtonian Fluid with a Higher Molecular Weight (Thicker fluid)

Non-Newtonian Fluid with a Lower Molecular Weight (Thinner Fluid)

Viscosity

Large Difference

(b) Low shear rate
Excellent Sensitivity

(c) High shear rate
Little Sensitivity

Philappoffian Region
An asymptotic plateau where the higher molecular and lower molecular shear rate/viscosity curves become close together.

In this region, sensitivity of viscosity measurement becomes significantly lower as the viscosity difference between the two curves becomes undistinguishable.

Very Small Difference

Measures at a low shear rate where the difference is much larger...this means much greater sensitivity

Competition
Measures at a high shear rate where the difference is smaller...this means lower sensitivity

(a) Zero shear rate
Best Sensitivity

End of Slide
## The TOV Viscometer System
### In-Line Viscosity Measurement

### TOV vs. Capillary Viscosity Formula

\[ \eta = \left( \frac{\pi r^4}{8 L Q} \right) \Delta P \]

\[ \eta = \frac{\text{Shear Stress}}{\text{Shear Rate}} \]

<table>
<thead>
<tr>
<th>Variables</th>
<th>Capillary</th>
<th>TOV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Requires precise measurement of variables</td>
<td>Few variables (all “in-line” and involve normal</td>
</tr>
<tr>
<td></td>
<td>off-line in sidestream.</td>
<td>process fluid).</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>Very Low (method, principle, and variables</td>
<td>Very High (produces “lab-like” results on a</td>
</tr>
<tr>
<td></td>
<td>restrict sensitivity)</td>
<td>real-time basis).</td>
</tr>
<tr>
<td>Output Signals</td>
<td>2 Pressure sensors measure the pressure in</td>
<td>Process Temperature, Uncompensated Viscosity,</td>
</tr>
<tr>
<td></td>
<td>the sidestream. Temperature from</td>
<td>Compensating Temperature, Compensated</td>
</tr>
<tr>
<td></td>
<td>temperature bath for the sidestream is</td>
<td>Viscosity, &amp; Pressure Compensation (on the</td>
</tr>
<tr>
<td></td>
<td>recorded.</td>
<td>viscosity signal).</td>
</tr>
<tr>
<td>Labor Requirements</td>
<td>Requires many tests and much maintenance.</td>
<td>Minimal. Process engineer/control room</td>
</tr>
<tr>
<td></td>
<td>Each test is prone to human error.</td>
<td>operator simply monitors output.</td>
</tr>
<tr>
<td>Sensing Device</td>
<td>Viscosity calculated by formula using</td>
<td>Special shape sensor is custom designed</td>
</tr>
<tr>
<td></td>
<td>pressure change in sidestream.</td>
<td>according to customer’s viscosity range.</td>
</tr>
<tr>
<td>Economics</td>
<td>Lower initial cost. Very high maintenance</td>
<td>More initial investment. Little continuing</td>
</tr>
<tr>
<td></td>
<td>costs. Lag time and/or process delays</td>
<td>maintenance costs . . . requires little or</td>
</tr>
<tr>
<td></td>
<td>waiting for results means lost or bad</td>
<td>no maintenance. Very few variables. No lag</td>
</tr>
<tr>
<td></td>
<td>product.</td>
<td>time and/or process delays, real-time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>results.</td>
</tr>
</tbody>
</table>

Contact Info

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The TOV Viscometer System
In-Line Viscosity Measurement

TOV viscosity readings...

TOV Output: Can Match the actual process changes...

Other In-Line Models Output:
Drift due to noise problems

Control Level (High)

Agitator Current: Almost No sensitivity

Control Level (Low)

Capillary: Little sensitivity
(See Capillary comparison)

Process Data

Graphical Representation for Illustrative Purposes Only

... in range and in control
## The TOV Viscometer System
### In-Line Viscosity Measurement

<table>
<thead>
<tr>
<th>Description</th>
<th>Mansco TOV</th>
<th>Other In-Line Models</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature Range</td>
<td>-40°C to 350°C</td>
<td>-40°C to 400°C Requires cooling system</td>
</tr>
<tr>
<td>Viscosity Range:</td>
<td>0.01 cP to 60,000* cP TOV customized to operate in narrow band within range.</td>
<td>10.0 cPs to 100,000 cPs 100 cPs to 1,000,000 cPs. .10 cPs. To 1,000 cPs. 1.0 cPs. To 10,000 cPs.</td>
</tr>
<tr>
<td>Sphere Rod LV Cylinder</td>
<td>* Based on internal tests</td>
<td></td>
</tr>
<tr>
<td>Accuracy</td>
<td>+/- 1% of reading</td>
<td>+/- 2% of reading</td>
</tr>
<tr>
<td>Repeatability</td>
<td>+/- 0.2% of reading</td>
<td>+/- 0.25% of reading</td>
</tr>
<tr>
<td>Vibration Influence error:</td>
<td>Negligible</td>
<td>Negligible with acceleration below: 0.5g, 50hz, 0.33g, 300hz 0.6g, 50hz, 0.8g, 300hz.</td>
</tr>
<tr>
<td>At 1 cP.</td>
<td>Factory calibrated, front panel access, on-line checks, built-in simulator</td>
<td>Requires calibration and rear access, does not offer on-line checks or simulator</td>
</tr>
<tr>
<td>At 1,000 cPs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electronics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shear Rate</td>
<td>700 sec(^{-1})</td>
<td>4400 sec(^{-1})</td>
</tr>
<tr>
<td>Frequency</td>
<td>Approx. 115 Hz</td>
<td>Approx 700 Hz</td>
</tr>
</tbody>
</table>

**TOV Advantage**
- Higher Temperatures without special installation.
- Other In-lines measure viscosity in a broad range – TOV designed to measure over a smaller range increasing sensitivity and accuracy.
- Other in-line models operate at higher shear rates – TOV at a low shear rate meaning much greater sensitivity to real viscosity changes.
- In head-to-head comparative tests, Other in-line models were found to be insensitive to viscosity changes and deemed not useful.

**TOV designed for customers viscosity range**

**TOV operates at a low shear rate, meaning much greater sensitivity.**

**TOV won in head to head comparison tests.**

**TOV does not require extra cooling...even at 350°C**

**TOV eliminates noise concerns...eliminates drift of measurement.**
Summary...  

√ The TOV Probe:  
  ▪ Designed for pressures over 10,000psi and temperatures up to 350°C  
  ▪ Contoured to match the pipeline  
  ▪ No motors or gears….means low maintenance  

√ The TOV Adaptor:  
  ▪ Designed per customers requirements  
  ▪ Not limited by pipe sizes, materials, or schedules  
  ▪ Smooth contoured for no process built-up  

√ The TOV Advantage:  
  ▪ In-line (in the main process line or vessel), real-time measurements  
  ▪ Better sensitivity than capillaries and other at-line instruments  
  ▪ Tighter process control = better quality = less lost product = better price
The TOV Viscometer System
In-Line Viscosity Measurement

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