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DROPLET SIZE AND VELOCITY MEASUREMENTS
for Tav-Tech Ltd

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DROPLET SIZE AND VELOCITY MEASUREMENTS

PDPA/LDV measurements

TSI, Incorporated the Phase Doppler Particle Analyzer/Laser Doppler Velocimeter (TSI PDPA/LDV) system is an optical technique to simultaneously measure the size and velocity particles. These particles can be droplets, bubbles or solid particles, as typically occur in sprays, liquid atomization, bubbly two-phase flows and multiphase flows.

PDPA systems are used in a wide variety of disciplines around the world. Following is just a few examples of areas where TSI PDPA systems have been used:

1. **Combustion research**: Measurement of fuel droplets.
2. **Aircraft icing research**: Measurement of water and ice drops and their affect on aircraft
3. **Ink-jet printer development**: Improve performance of ink-jet printers. Both size of drops and the trajectories of drops being fired are measured.
4. **Basic industrial sprays research**: PDPA is used to characterize various chemicals that are atomized (pesticides, petrochemicals, etc.).
5. **Spray drying**: Used in pharmaceutical and food applications.
6. **Characterization of Metered Dose Inhalers (MDI's)**: Characterize the size and velocity of droplets produced by medical inhalers.
7. **Paint sprays**: Characterization of drop size distributions

A fiber based laser measurement TSI Inc. Phase Doppler Particle Analyzer/Laser Doppler Velocimeter (TSI PDPA/LDV) system was used for the measurements. It contains the following major components (shown on Figure 1):

- Laser light source - the system is integrated by Ar-laser (2017 model).
- Light separation optics - Fiberlight Multi-color Beam Separator generates the laser beams needed for two- or three-component PDPA systems and couples the laser light into the transmitting optics for delivery to the measuring volume.
- Light transmitting optics
- Light collecting optics - Fiberoptic Receivers have several unique features that make them ideal for particle size and velocity measurements. By utilizing a fiber bundle instead of individual fibers for
light collection, the TSI Fiberoptic Receivers are easy to align and provide high optical efficiency. Integration of the calibration diode light back through the receiver provides an optimum phase calibration for ensuring the accuracy of particle size measurements.

- **Photodetectors** - Photodetector Module (PDM) system combines an enhanced scattered light separation unit with high performance photomultiplier tubes and initial signal conditioning electronics. The PDM is optimized for high dynamic range and is software controlled.

- **Signal processing electronics** - Flow and Size Analyzer (FSA) processors are the fastest, most accurate ever developed for PDPA applications. Utilizing a firmware based approach and two powerful digital processing techniques, FSA processors are optimized for different PDPA applications. Data transfer is done via the FireWire (IEEE 1394) standard interface.

- **External data input devices** - A compact multi-channel interface that lets combine pressure, temperature or similar analog or digital data with the velocity measurements. For periodic or pulsatile flows, the device also may collect encoder or phase angle information for phase-locked data acquisition and analysis.

- **Computer** - Systems run on Windows based PC computer, through the FireWire communication interface.

- **Software** - FlowSizer Data Acquisition and Analysis Software is used for set-up, control and operation of PDPA systems.

![Figure 1 TSI PDPA/LDV system](image-url)
Major measured parameters

Velocity Statistics provides the mean and the root-mean-square (RMS) values of velocity for each component. The turbulence intensity is the ratio of RMS to mean velocity expressed in percent. The system measures two components of velocity, vertical and horizontal. Its combination with X, Y, Z-traverse system yields a unique capability to execute measurements of radial and tangential component velocity of droplets in spray.

Velocity Mean (m/s): The average velocity value of all the velocities measured

\[
\bar{V} = \frac{\sum_{i=1}^{n} V_i}{n}
\]

\(V_i\) = Velocity for \(i\)-particle,
\(n\) = number of particles.

Velocity RMS (m/s): Standard deviation of the velocities measured

\[
V_{RMS} = \sqrt{\frac{\sum_{i=1}^{n} (V_i - \bar{V})^2}{n - 1}}
\]

The diameter statistics consist of various mean diameters, i.e., number mean \(D_{10}\), surface mean \(D_{20}\), volume mean \(D_{30}\), Sauter mean \(D_{32}\) and \(D_{43}\). The following general definition applies to all of the above mean diameters:

\[
D_{mn} = \left(\frac{\sum D^m}{\sum D^n}\right)^{\frac{1}{m-n}}
\]

Example: \(D_{32}\) (um) or the Sauter Mean Diameter (SMD):
\[ D_{32} = \frac{\sum_{i=1}^{n} D_i^3}{\sum_{i=1}^{n} D_i^2} \]

\( D_i \) = diameter of \( i \)-particle,
\( n \) = number of particles.

In Table 1 the particle diameter measurement range (in the Technion’s systems), depending on lens focal lengths of transmitter and receiver units sand at different refraction index values, \( N \), presented.

### Table 1 Range of measured droplet diameter by PDPA system

<table>
<thead>
<tr>
<th>Ar-laser, 514.5 nm</th>
<th>Water droplets, ( n = 1.332 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>TR260-X10 Transmitter</td>
<td>RV2070 Receiver</td>
</tr>
<tr>
<td>Lens focal length, mm</td>
<td>Lens focal length, mm</td>
</tr>
<tr>
<td>Min. Diameter</td>
<td>Max. Diameter</td>
</tr>
<tr>
<td>um</td>
<td>um</td>
</tr>
<tr>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>0.8</td>
<td>350</td>
</tr>
</tbody>
</table>

**Measurement results**

Measuring the sizes and mean velocity of the droplets were performed on the axis of the water jet at distance \( H = 10 \) mm and 20 mm from the nozzle. 20,000 droplets were measured at each point. Measurement results are presented in Figures and Table 2.

**Note**

It should be indicated that the velocity field in the volume of the spray is highly turbulent and 3 dimensional.

The size and velocity histogram represents the information collected at a specific point downstream of the nozzle. The size histogram represents the global histogram of about 20,000 droplets of a wide diameter range and the velocity histogram represents the global histogram of all droplets of all size ranges at the specific location. However, each size group of the droplets has its own mean and RMS velocity values. These can be seen through the chart displaying the size to velocity correlation.
1. JP1-N23 handpiece, JetPeel device, air pressure ~95psi

Run 11, H = 10mm
Run 10, H = 20mm
Run 28, H =10mm, glycolic acid 5% (n = 1.424). In experiment n = 1.33.
Run 29, H = 20mm, glycolic acid 5% (n = 1.424). In experiment n = 1.33.
2. JP1-N01 handpiece, JetPeel device, air pressure ~95psi

A) The laser control volume is located in the plane of three nozzles

Run 14, H = 10mm
Run 13, H = 20mm
B) The laser control volume is located perpendicular to the plane of three nozzles

Run15, H =10mm
Run 17, H =20mm
3. JP1-N05 handpiece, JetPeel device, air pressure ~95psi

Run 23, H = 10mm
Run 19, H = 20mm
4. JND-011 Jetox-ND The cleansing and debridement system, air pressure ~50psi

Run 25, H = 10mm
Run 24, H = 20mm
5. MJT-250 MedJet Irrigator, air pressure ~50psi

Run 34, H = 10mm
Run 33, H = 20mm
Table 2 Spray parameters for different nozzles

<table>
<thead>
<tr>
<th>Nozzle</th>
<th>Liquid</th>
<th>H, mm</th>
<th>Run</th>
<th>D10, um</th>
<th>D32, um</th>
<th>Vel. Mean, m/s</th>
<th>Velocity RMS (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 1 JP1-N23</td>
<td>Water</td>
<td>10</td>
<td>11</td>
<td>10.17</td>
<td>12.49</td>
<td>205.6</td>
<td>4.8</td>
</tr>
<tr>
<td>3 JP1-N23</td>
<td>glycolic acid 5%</td>
<td>10</td>
<td>28</td>
<td>11.64</td>
<td>16.65</td>
<td>203.7</td>
<td>21.5</td>
</tr>
<tr>
<td>4 JP1-N23</td>
<td>glycolic acid 5%</td>
<td>20</td>
<td>29</td>
<td>10.45</td>
<td>16.36</td>
<td>209.1</td>
<td>23.8</td>
</tr>
<tr>
<td>5 2 JP1-N01, parallel</td>
<td>Water</td>
<td>10</td>
<td>14</td>
<td>13.90</td>
<td>20.54</td>
<td>210.3</td>
<td>13.4</td>
</tr>
<tr>
<td>6 JP1-N01, parallel</td>
<td>Water</td>
<td>20</td>
<td>13</td>
<td>16.15</td>
<td>19.24</td>
<td>192.6</td>
<td>30.1</td>
</tr>
<tr>
<td>7 JP1-N01, perpendicular</td>
<td>Water</td>
<td>10</td>
<td>15</td>
<td>16.23</td>
<td>19.03</td>
<td>166.8</td>
<td>33.1</td>
</tr>
<tr>
<td>8 JP1-N01, perpendicular</td>
<td>Water</td>
<td>20</td>
<td>17</td>
<td>15.33</td>
<td>18.12</td>
<td>182.2</td>
<td>33.1</td>
</tr>
<tr>
<td>9 3 JP1-N05</td>
<td>Water</td>
<td>10</td>
<td>23</td>
<td>14.44</td>
<td>18.66</td>
<td>219.3</td>
<td>30.9</td>
</tr>
<tr>
<td>10 JP1-N05</td>
<td>Water</td>
<td>20</td>
<td>19</td>
<td>13.41</td>
<td>16.26</td>
<td>140.9</td>
<td>33.3</td>
</tr>
<tr>
<td>11 4 JND-011 Jetox-ND</td>
<td>Water</td>
<td>10</td>
<td>25</td>
<td>15.00</td>
<td>20.19</td>
<td>204.5</td>
<td>17.7</td>
</tr>
<tr>
<td>12 JND-011 Jetox-ND</td>
<td>Water</td>
<td>20</td>
<td>24</td>
<td>14.89</td>
<td>18.56</td>
<td>155.1</td>
<td>30.6</td>
</tr>
<tr>
<td>13 5 MJT-250 MedJet</td>
<td>Water</td>
<td>10</td>
<td>34</td>
<td>11.42</td>
<td>14.56</td>
<td>77.5</td>
<td>30.8</td>
</tr>
<tr>
<td>14 MJT-250 MedJet</td>
<td>Water</td>
<td>20</td>
<td>33</td>
<td>11.35</td>
<td>14.57</td>
<td>63.9</td>
<td>22.9</td>
</tr>
</tbody>
</table>