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DEPARTMENT OF AEROSPACE ENGINEERING

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UNIT I - INTRODUCTION TO AIRCRAFT PROPULSION

Atomization and Spray Formation Principles

Atomization and spray systems have a wide range of applications, such as in combustion devices like jet propulsion engines, diesel engines, industrial boilers, and furnaces. Atomization generally refers to a process in which a bulk liquid is disintegrated into small drops or droplets by internal and/or external forces as a result of the interaction between the liquid and the surrounding medium. The disintegration or breakup occurs when the disruptive forces exceed surface tension forces. External forces, such as aerodynamic forces, surface shear forces, centrifugal forces, and electrostatic forces, acting on the liquid surface may distort the bulk liquid and promote disruption. External forces may lead to oscillations and perturbations of the interfaces. These oscillations may be amplified and result in the breakup of the liquid into small droplets. This initial breakup process is often referred to as the primary breakup or the primary atomization. A population of larger droplets produced in the primary atomization may be unstable if they exceed a critical droplet size and thus may undergo further disruption into smaller droplets. This process is usually termed as the secondary breakup or the secondary atomization. Therefore, the final droplet size distribution produced in an atomization process is determined by the flow characteristics and the properties of the fluids in both the primary and secondary disintegration.

Atomization Fundamentals

Atomization Sprays, Droplets, and Surface Tension

Atomization refers to the process of breaking up bulk liquids into droplets. Common home atomizers you may be familiar with include shower heads, perfume sprays, garden hoses, and deodorant or hair sprays. A classic example of atomization occurring naturally involves pouring liquid from a pitcher. As you are pouring and gradually lift the pitcher higher, the stream of liquid elongates and breaks into droplets at some point. This breakup of a liquid stream is a simplistic example of atomization. See Figure 1 for an illustration of this concept.

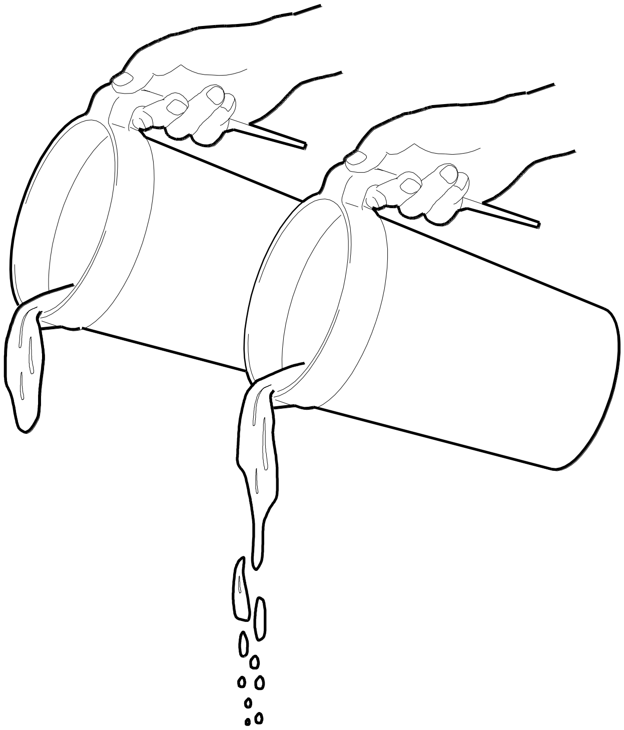

Figure 1 Atomization of a stream of liquid

A spray is a collection of moving droplets that usually are the result of atomization; they are moving in a controlled fashion. Naturally occurring sprays are rain and ocean sprays. See Figure 2 for a depiction of a spray from a gun. Note that there are a variety of droplet sizes in the spray.

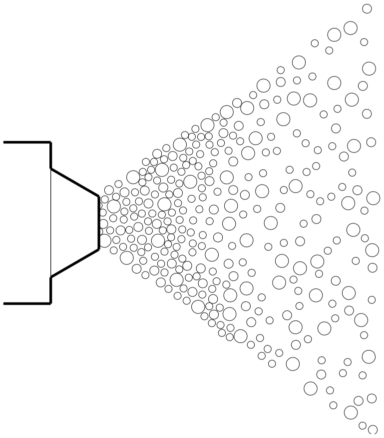

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Figure 2 A spray stream with a variety of droplet sizes

A droplet is a small particle of liquid having a more or less spherical shape. Droplets are also known as particles.

The reason particles are round is due to the liquid's surface tension. Recall that surface tension is the property of a liquid that causes droplets and soap bubbles to pull together in a spherical form and resist spreading out. This property causes sheets or thin ligaments of liquid to be unstable; that is, they break up into droplets, or atomize.

Have you ever accidently broken a thermometer and observed how mercury beads up? Mercury's resistance to spreading out is evidence of its high surface tension. You also may have observed this phenomenon with water; it has a tendency to bead up into droplets, especially on a waxed surface, like a car. The chart in Figure 3 lists a number of common materials and their surface tensions.

As the temperature of a liquid increases, its surface tension generally decreases. This becomes an important factor when handling certain fluids.

Surface Tension of Common Fluids	
Liquid	**Surface Tension (Newton/meter at 20°C)**
Ethyl alcohol	0.022
Soapy water	0.025
Benzene	0.029
Olive oil	0.032
Lubricating oil	0.037
Glycerine	0.063
Water	0.073
Mercury	0.465

Figure 3 Surface tension of familiar liquids

Fluid Properties Affecting the Spray

A variety of factors affect droplet size and how easily a stream of liquid atomizes after emerging from an orifice. Among these factors are fluid properties of surface tension, viscosity, and density.

Surface Tension

Surface tension tends to stabilize a fluid, preventing its breakup into smaller droplets. Everything else being equal, fluids with higher surface tensions tend to have a larger average droplet size upon atomization.

Viscosity

A fluid's *viscosity* has a similar effect on droplet size as surface tension. Viscosity causes the fluid to resist agitation, tending to prevent its breakup and leading to a larger average droplet size. Figure 4 represents the relationship among viscosity, droplet size, and when atomization occurs.

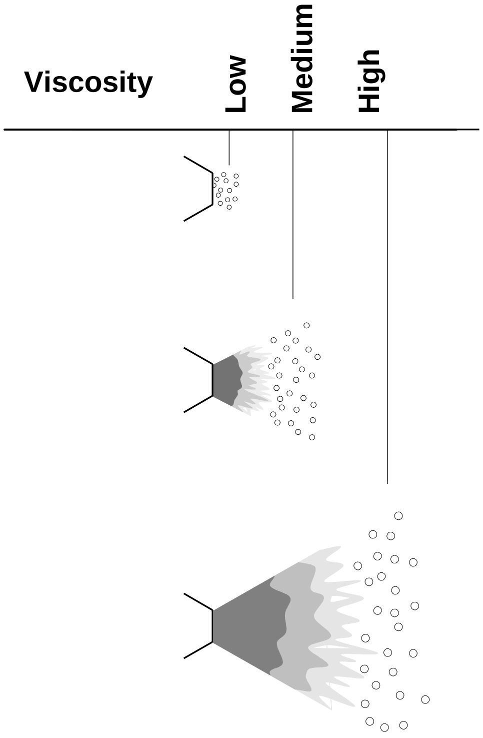

Figure 4 Viscosity, droplet size, and when atomization occurs

Density

Density causes a fluid to resist acceleration. Similar to the properties of both surface tension and viscosity, higher density tends to result in a larger average droplet size.

Atomization Processes

Pressure (Airless) Atomization

Other terms the spray coating industry uses for pressure atomization include airless, air-assisted airless, hydrostatic, and hydraulic technology.

In the airless atomization process, high pressure forces fluid through a small nozzle. The fluid emerges as a solid stream or sheet at a high speed. The friction between the fluid and the air disrupts the stream, breaking it into fragments initially and ultimately into droplets.

The energy source for this form of atomization is fluid pressure, which is converted to momentum as the fluid leaves the nozzle.

Three factors that affect an airless spray include the atomizer orifice diameter, the atmosphere, and the relative velocity between the fluid and the air. Regarding orifice diameter, the general rule is that the larger the diameter or size of the atomizer orifice, the larger the average droplet size in a spray.

The atmosphere provides resistance and tends to break up the stream of fluid. This resistance tends to overcome, in part, the fluid’s properties of surface tension, viscosity, and density. In addition, the air temperature may also affect atomization.

The relative velocity between the fluid and the air also affects droplet sizes. The fluid’s velocity is created by pressure in the nozzle. As the fluid pressure increases, velocity increases and the average droplet size decreases. And conversely, as fluid pressure decreases, velocity is lower and the average droplet size is larger.

Figure 5 illustrates a simple circular orifice injecting a round stream of fluid into the atmosphere. The fluid is under pressure and is breaking up into a spray.

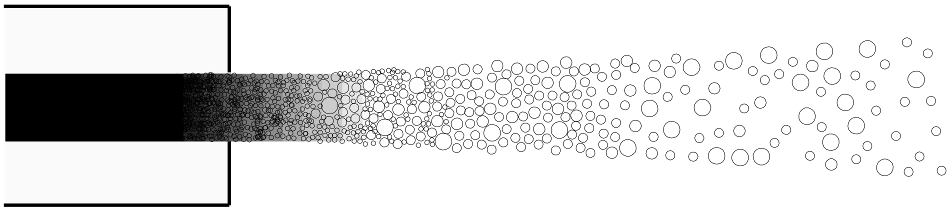

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Figure 5 Airless atomization with fluid under pressure

Air (Air Spray) Atomization

In air spray atomization, fluid emerging from a nozzle at low speed is surrounded by a high speed stream of air. Friction between the liquid and air accelerates and disrupts the fluid stream and causes atomization.

The energy source for air atomization is air pressure. The operator can regulate the flow rate of fluid independently of the energy source. Figure 6 illustrates a stream of fluid passing through an orifice; as it emerges, a high speed stream of air surrounds the fluid stream. Note that other modules will cover the function of the horns you see on the illustration and the resulting spray patterns.

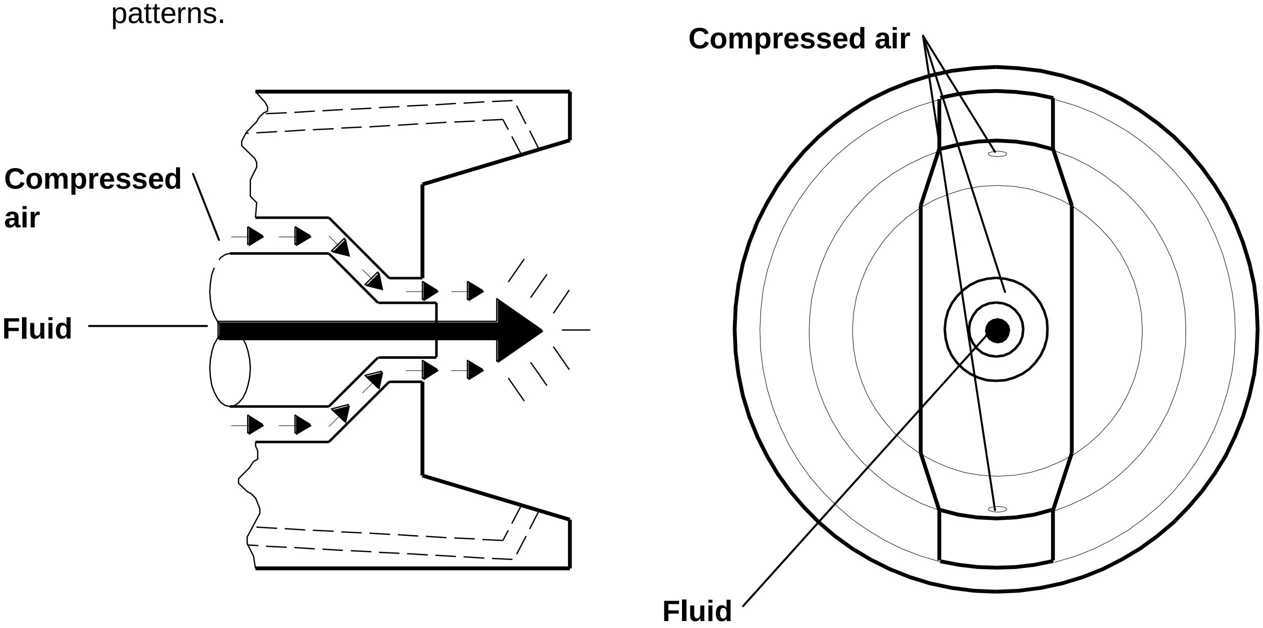

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Figure 6 Air spray atomization with high-velocity air

Note that sometimes you will hear the term conventional instead of air atomization. Use of the word conventional is often ambiguous since many industry people use this term to refer to all non-electrostatic applications.

Recall that it is the relative difference in velocity between fluid and air that causes atomization. Review the chart in Figure 7 for a summary of this concept for airless and air spray atomization. Then see Figure 8 which depicts a high-velocity water jet (airless atomization).

Relative Initial Velocity	**Air**	**Fluid**
Airless Atomization	Slow	Fast
Air Spray Atomization	Fast	Slow

Figure 7 The relative velocities of air and fluid for airless and air spray atomization

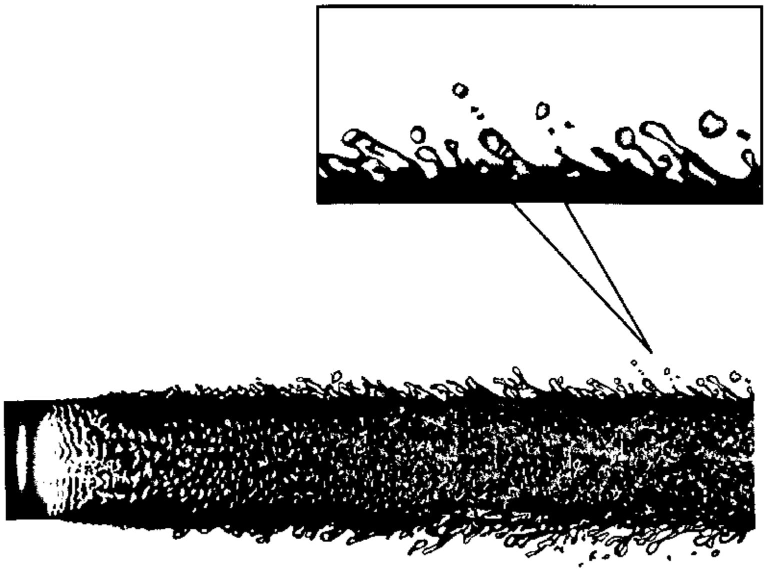

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Figure 8 A high-velocity water jet that is breaking up by airless atomization

Centrifugal Atomization

In centrifugal or rotary atomization, a nozzle introduces fluid at the center of a spinning cup or disk. Centrifugal force carries the fluid to the edge of the disk and throws the fluid off the edge. The liquid forms ligaments or sheets that break into fine droplets. Figure 9 shows the mechanism of centrifugal atomization.

The energy source for rotary atomization is centrifugal force. With the same rotational speed, at low flow rates, droplets form closer to the edge of the disk than with higher flow rates. The spray pattern tends to move radially away from the disk or cup in all directions (360˚).

With rotary atomization, operators can control both the flow rate and the disk speed independently of each other. In most spray coating rotary applications, electrostatic charge is applied to the spray to attract the droplets to a grounded target object. In some types of atomizers, such as bells, shaping air can be added to move the spray forward in an axial direction.

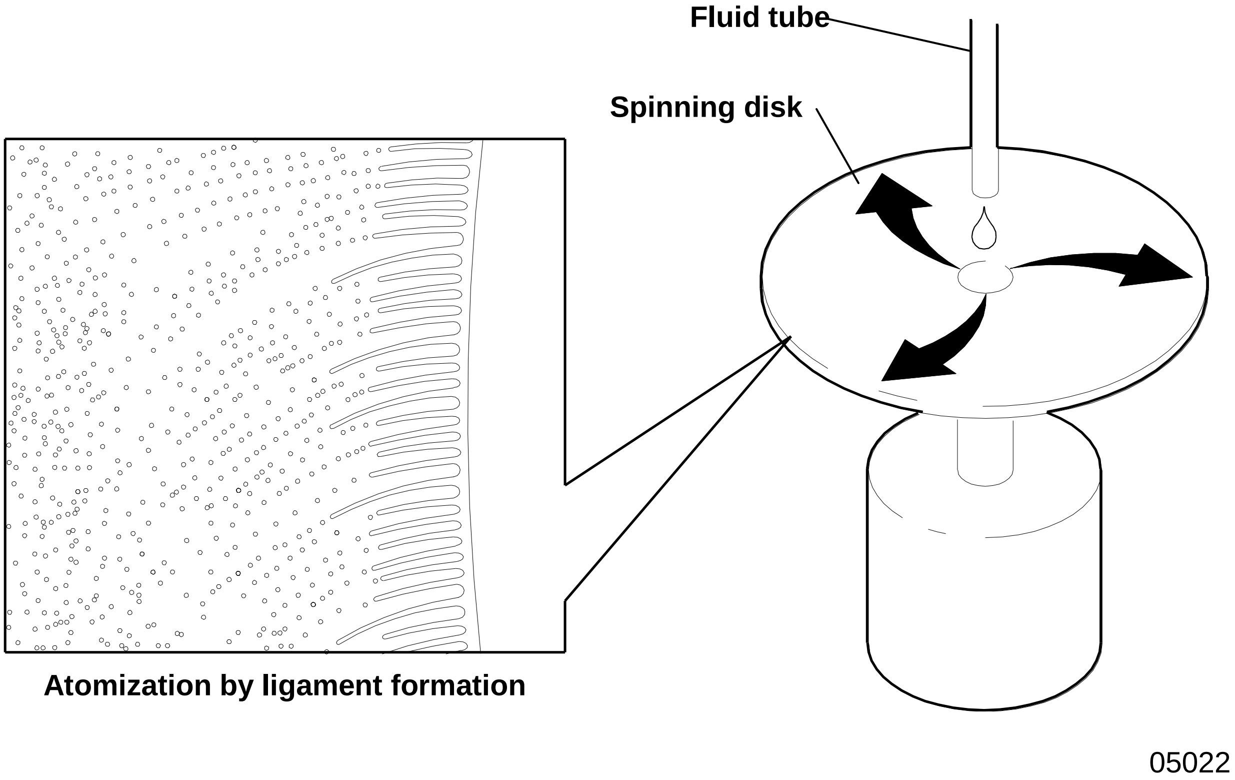

Figure 9 Centrifugal atomization

Electrostatic Atomization

Electrostatic atomization exposes a fluid to an intense electric field between the charged atomizer and grounded work piece. The charge transfers to the fluid and repulsive forces between the atomizer and the fluid tear the droplets from the atomizer and send them toward the work surface. See Figure 10 for an illustration of the concept of electrostatic atomization.

The energy source for electrostatic atomization is the electric charge that the fluid receives. The particle size with electrostatic atomization is a function of three main factors:

- Electric field strength
- Liquid flow rate
- Fluid properties (including its electrical properties)

It is important to understand the distinction between electrostatic atomization and electrostatic spray charging. With electrostatic atomization, electrostatic forces are used to atomize the fluid. In electrostatic spray charging, the spray is usually atomized by airless, air spray, or rotary means, and electrostatic charge is applied to the droplets as they form to help attract them to the work surface.

Note, however, that electrostatic atomization is not successful for current high viscosity coatings.

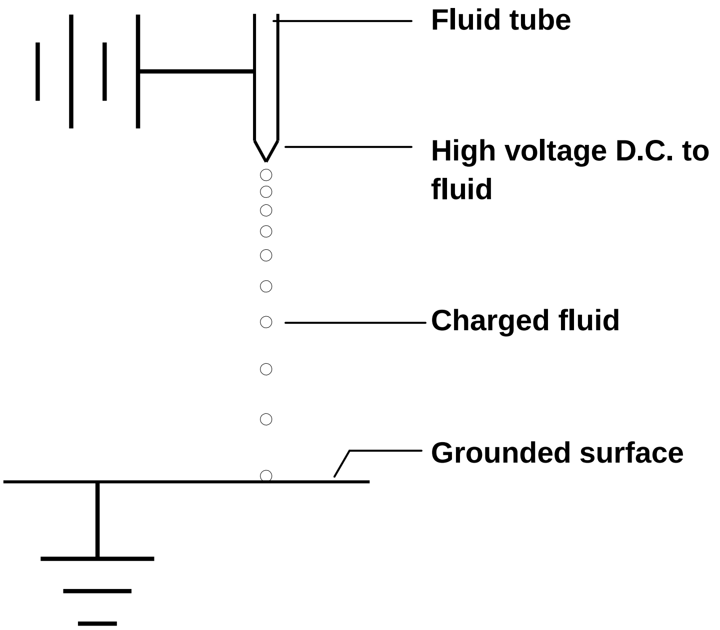

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Figure 10 Electrostatic atomization

Ultrasonic Atomization

Although it is uncommon to find this atomization process in the spray coating industry, competitors periodically introduce new “ultrasonic” technologies. It is important to understand the process to evaluate new technologies and counter competitors’ claims effectively.

Ultrasonic atomization relies on an electromechanical device that vibrates at a very high frequency. Fluid passes over the vibrating surface and the vibration causes the fluid to break into droplets. Figure 11 shows an example of ultrasonic atomization technology.

Applications of this technology include:

- Medical nebulizers for inhalation therapy
- Drying liquids; powdered milk for example, in the food industry
- Surface coatings in the electronics industry

Ultrasonic atomization technology is effective only for low-viscosity Newtonian fluids. It has not been successfully commercialized for paint.

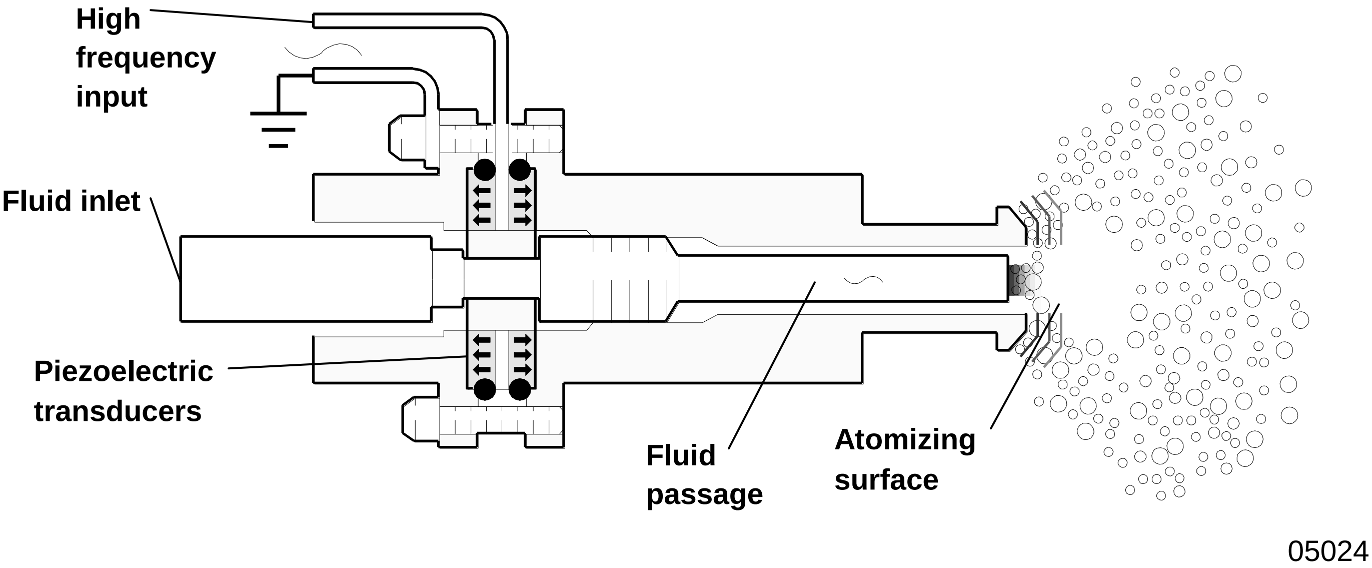

Figure 11 Ultrasonic atomization technology

Achieving Desired Atomization

Achieving the desired level of atomization requires maintaining a balance of the fluid viscosity and quantity (fluid flow rate) on one side with atomization energy on the other side. Figure 12 shows a fulcrum that schematically illustrates the necessary balance.

Once the system (or operator) achieves the desired level of atomization, a change in any parameter will affect the atomization. Balancing the equilibrium with an opposing change can return the atomization to the desired level.

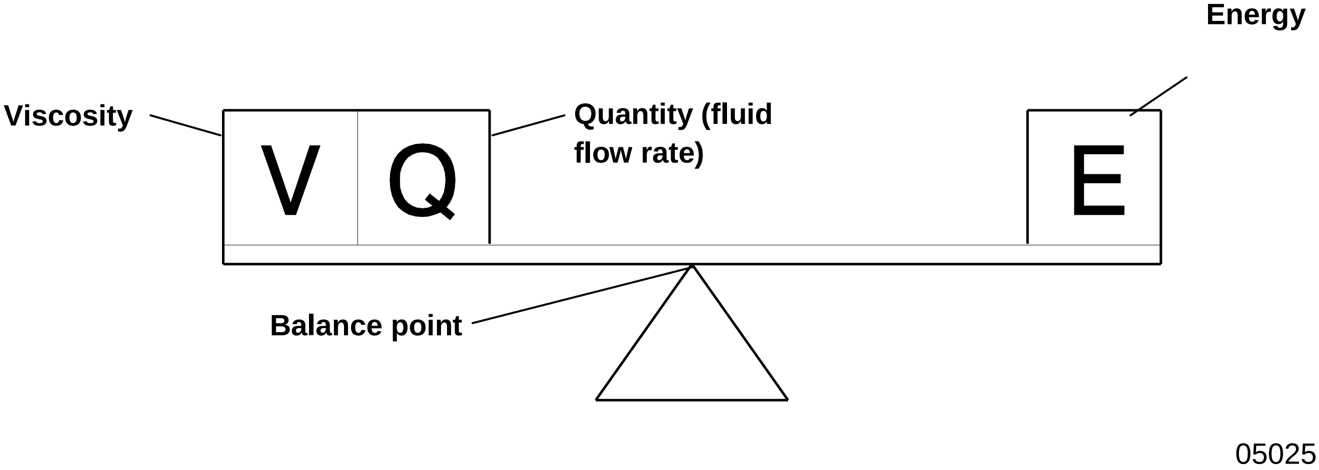

Figure 12 Balancing factors to achieve desired atomization

Review the chart in Figure 13 for a summary of the energy sources for the atomization processes used in Graco equipment.

Atomization Processes	Energy Sources
Pressure (airless, air-assisted airless)	Fluid pressure
Air (air spray)	Air spray
Centrifugal (rotary)	Centrifugal force (motor)

Figure 13 Atomization processes and their energy sources