Benefits of Pressure Regulation in Irrigation

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ABSTRACT

The use of pressure regulation in irrigation design can significantly improve system efficiency by limiting pressure fluctuation that reduces distribution uniformity (DU). With increasing emphasis on water and energy conservation, many systems are being designed or converted to lower pressure. As a result, system pressure variations have become a larger percentage of the total, requiring more precise regulation.

A standard irrigation design objective is to take a predetermined amount of water and apply it uniformly over a fixed area. Uncontrolled pressure fluctuations into sprinklers or emitters result in unwanted flow deviations and pattern distortions. Various types of pressure regulators are available to meet specific flow and pressure requirements. These relatively low cost devices can dramatically improve system performance. Understanding the effect that pressure control has on irrigation system performance and knowing the fundamentals of pressure regulator operation and application is essential for irrigation system designers and growers.

INTRODUCTION

The availability of water worldwide for irrigation is decreasing. Half of the world's fresh water supplies are being depleted faster then they can be replenished. Currently about 70% of the world's available fresh water supply is being used for irrigation. Several factors are driving the demand for water, the most significant of which is food production needed to feed a rapidly expanding population. Additionally, changes in population demographics, especially in the developing world, have led to a shift to higher protein diets requiring greater water inputs and further exacerbating water demand. Consequently, the agricultural community has an enormous impact on water conservation. Unfortunately, 90% of irrigation systems are based on inefficient methods of irrigation. This means that conversion of these wasteful systems to more efficient mechanized or drip systems has the potential to produce water savings of 50% or more (William Blair & Company, 2009).

Government is also playing an increasing role in the use of water and the future direction of the irrigation industry. Regulation and subsidies aimed at water conservation are driving the switch to more efficient irrigation systems. New technologies and innovations in irrigation will be used to lower cost and improve yields of not only food production but also agricultural products such as alternative fuels. Pressure regulators are at the forefront of irrigation technology and the efficient use of water resources.

BENEFITS OF PRESSURE REGULATION

Uniformity

One major reason to regulate system pressure is to maintain high uniformity. A basic irrigation design objective is to take a predetermined amount of water and apply it uniformly over a given area. Why should growers be concerned with irrigation system uniformity? Allowing uncontrolled pressure fluctuations into sprinklers or emitters will result in unwanted flow deviations. Uniform water application is necessary to maximize system efficiency (Haman and Yeager, 1998)**.** Therefore,

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maintaining constant pressure throughout the irrigation system is critical for the uniform distribution of water.

The total pressure variation in a well designed irrigation system should not exceed 20%. As the irrigation industry continues to move towards more efficient lower pressure system designs, the impact of system pressure variations have become a larger percentage of the total system pressure, requiring more precise regulation.

Flow (discharge) and Pressure Relationship:

> New Flow Rate = Old Flow Rate Multiplied by the Pressure Ratio (Square Root of the New Pressure Divided by the Old Pressure)

The following simplified equation can be used for pressure ratios less than 1.5:

> The Percentage of Flow Variation Equals Half the Percentage of Pressure Variation (Sprinkler Irrigation 4th Edition). Therefore, when system pressures vary by 20%, system flow will vary by 10%.

Uniformity of water application of sprinkler irrigation systems is commonly reported as Distribution Uniformity (DU). It is an indicator of how consistent the application rates are in the system. In nursery applications a DU of 60% or below is considered low and indicates that application rates vary greatly. A system DU of 80% or greater is considered high and indicates consistent water distribution. DU is based on the low quarter of the irrigated area. For high value crops, 80% DU is a minimum (Haman and Yeager, 1998)**.**

> DU = (Average Low Quarter Depth / Overall Average Depth) x 100%

In the following example, the average seasonal irrigation requirement of Corn grown in Minnesota is 11-inches. The design parameters include impact sprinklers on a center pivot irrigating 100 acres with a system distribution uniformity of 70%..

> Irrigation Requirement = Plant requirement / Uniformity

Table 1: Irrigation requirements based on system distribution uniformity

Plant Requirement	**Uniformity**	**Irrigation Requirement**	**Gallons per Acre Inch**	**Irrigated Acres**	**Gallons/ year**
11 inches	70%	15.7 inches	27,154	100	42,631,780
11 inches	85%	12.9 inches	27,154	100	35,140,470

This example illustrates that by increasing uniformity from 70% to 85%, an 18 percent decrease in water use can be achieved (Table 1). Higher system uniformity results in less water required to irrigate the crop, lower pumping costs, reduced risk of leaching chemicals, and runoff. (Mathers 2003)

<u>Irrigation System Considerations</u>

System pressures will vary throughout the system due to friction loss through pipes, fittings and elevation changes. When operating conditions change from one system block or zone to another, or if different combinations of these subsets will be operated simultaneously, regulators may be required.

Mechanical move systems may have an end gun or corner arm which acts as a separate zone, and when turned on or off will dramatically change system pressure. In solid set applications, the pipe diameters and elevation do not change once the system is installed. However, mechanical move systems are not stationary and they have the potential to experience elevation (Figs. 1a, 1b) and pressure changes during operation that in turn could cause flow variations greater than 10%. Furthermore, some mechanical move systems are designed to be moved from one area to another, potentially adding additional pressure and flow variations. Proper placement of pressure regulators in these applications (scenarios) can provide constant pressures to the irrigation system, a zone, individual lateral lines, and/or any combination of positions and prevent variations from affecting the irrigation uniformity. (Clark, Stanley, and Smajstrla, 2002)

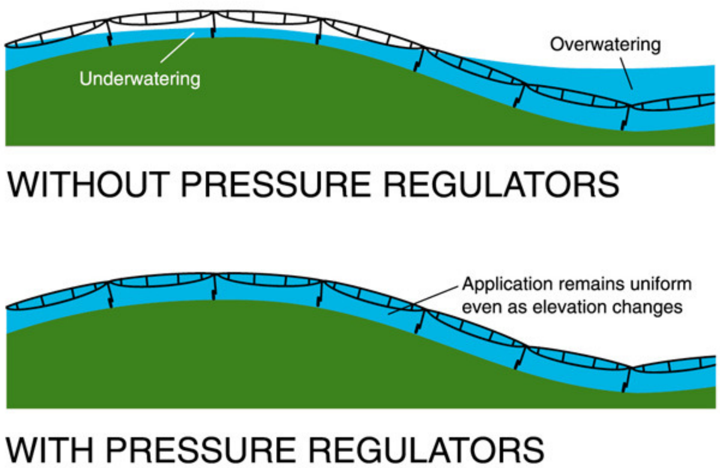


Fig. 1a: The effects of elevation on an unregulated center pivot.

Fig. 1b: A photo showing a center pivot operating across varying field elevations.

Sprinkler Considerations

Sprinkler uniformity can be affected by head spacing, flow, and pressure. Changes in pressure directly impact sprinkler flow rates resulting in variable application rates within the defined area. Poor uniformity due to flow variations is compounded by the effects of pressure on sprinkler patterns. Pressure fluctuations outside the intended system design parameters will produce pattern distortions and other irregular sprinkler operation and performance characteristics. Beyond the design pressure parameters, operating a sprinkler outside of the manufacturer's recommended ranges can produce extreme sprinkler performance abnormities and possible sprinkler or system damage. Operating pressures that are too high will generate very small droplets (fogging) susceptible to wind drift, irregularly large amounts of water near the head, and changes in rotational speed (Fig. 2a, 2b). If the pressure is too, low donut shaped patterns (Fig. 2c) and dry spots near the heads may form. The result in either case is lower sprinkler and system uniformity. (4 Haman, Smajstrla, and Pitts, 2003)

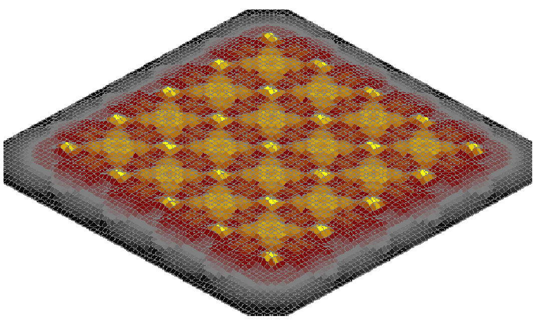
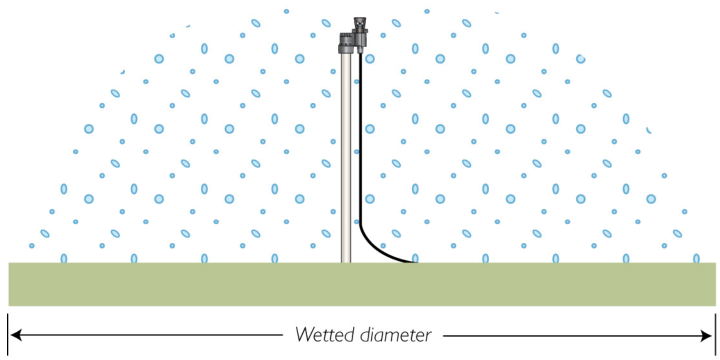


Fig. 2a: Sprinkler densogram at the design pressure showing relatively even distribution.



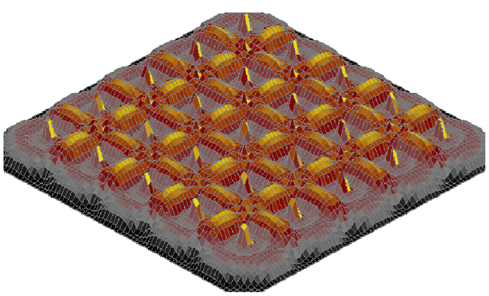


Fig. 2c: Sprinkler densogram showing donut shaped pattern distortions when the system pressure drops below allowable limits.

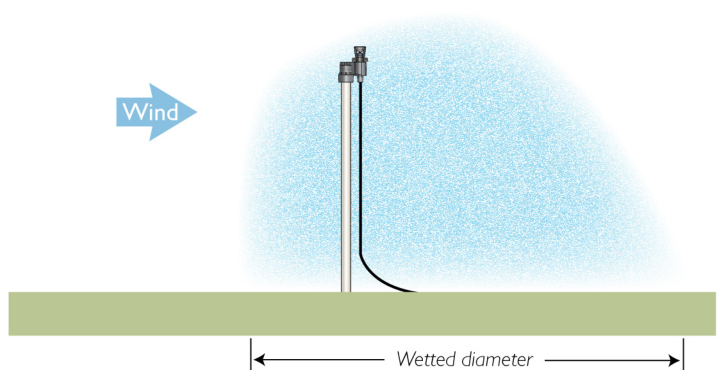


Fig. 2b: Wind effects on droplet size

Excessive pressure increases flow which can cause runoff. Irrigation systems should be designed below the minimum infiltration rate of the soil to avoid runoff. A system designed with uniformity, as one of its criteria, can help achieve this goal. (Mathers, 2003).

For Example, mini-Wobblers® irrigating a solid set field for vegetable production is designed to operate at 15 psi with a flow rate of 1.67 gpm on a spacing of 25 x 25 ft. yielding an application rate of 0.25 inches per hour over a defined area of 350 ft. x 350 ft. The infiltration rate of the soil has been determined to be 0.25 inches per hour. However, one of the laterals has developed a leak and is shut off for repair but the zone is still activated. This results in an increase in pressure of 20% which translates into 10% increase of sprinkler flow rate, thus raising the application rate to 0.28 inches per hour. Exceeding the soil infiltration rate increases the potential for runoff." (Mathers 2005)

System Life Expectancy

When system pressure exceeds the manufactures recommended range, some system components may fail or exhibit unacceptable performance characteristics. Most low-volume tubing or tape products have a maximum pressure rating to prevent product damage or failure. Pressure compensating products require a specific inlet pressure range to function properly, which if exceeded, will cause flow variation to exceed design tolerances.

Pressure regulators may be required if the pressure produced by the pump is too large or if zones vary greatly in flow. Often, when a system is retrofitted with lower pressure sprinklers, the pump portion of the existing system is not changed. This could cause the system to operate at pressures which are excessive for the new components. The pump must deliver the amount of water required in the largest zone at the pressure required. If the zones are not equally sized, the pump will deliver higher pressure at the smaller discharges required by these zones. Pressure regulators must be used to provide the lower pressure required for lateral lines or other low pressure system components.

To ensure that irrigation systems will function safely, system components must be properly pressure-rated to match system pressure. (Smajstrla, Zazueta, and, Haman, 2002) In some cases this is not possible without the use of pressure regulators. Center pivot systems fitted with low pressure sprinkler packages may experience excessive pressures at the pivot point that exceed the drop hose rating. Pressure regulators can be used upstream of the hose to prevent premature failure (Fig. 3).

Fig. 3: Pressure regulators installed upstream of drop hoses.

Mechanical move system components have a range of pressures that provide long life and optimal performance. Exceeding the manufacturers recommended pressure can produce droplets that are highly susceptible to evaporation and wind drift. Additionally, nozzle steam velocities are increased causing accelerated sprinkler wear, especially on spray pads that are impacted continually in the same location. As system pressure is reduced stream velocity is also reduced and product longevity is increased. Adhering to manufacturer's maximum and minimum pressure recommendations is critical for long-term system life and optimum operation.

Not Everyone Needs Pressure Regulators

Acceptable pressure control of some systems can be achieved without pressure regulators. Factors affecting appropriateness of regulator use include; system design, elevation, and cost constraints. Pressure control on a flat ground irrigation installation with single or equal zones can be achieved through pipe sizing. In some instances flow control can be used in place of pressure regulation. However, pressure regulators are an important tool for optimizing system efficiency and cost.

ECONOMIC CONSIDERATIONS

Operational cost savings achieved though lower system pressures and higher system efficiency can be seen most visibly and directly in the form of lower pumping costs. The use of pressure regulators plays an important role in cost savings generated though lower energy systems. (Fig. 4). Lowering operating pressure saves energy. With the high cost of electricity and fuel, that translates to saving money. To take full economic advantage of lower pressure systems, uniformity of flow must be maintained. Irrigation systems operating at lower pressures are more susceptible to pressure variations. Pressure Regulators can be used to maintain consistent pressure resulting in uniform flow and better system efficiency.

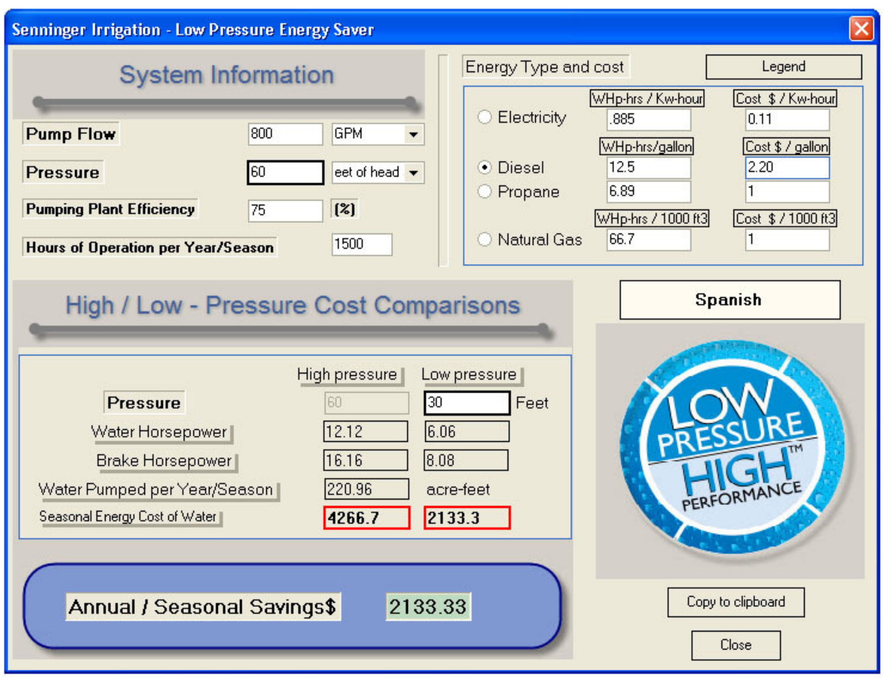


Fig. 4: Energy savings calculator available online

The Energy Saver calculator example shows that upgrading a conventional high pressure system to a more efficient low pressure system can save $2133/year. This represents a relatively short payback on the upgrade investment for a typical mechanical move sprinkler package with pressure regulators.

Labor availability and cost are other considerations. Manual valves will need to be adjusted to compensate for the pressure variations in an irrigation system, without pressure regulators, that experiences pressure fluctuations. Pressure regulators automatically regulate the pressure negating the need for manual system adjustment and the potential for human error that could cause non-uniform system performance and/or system damage.

Poor uniformity caused by pressure fluctuations will affect crop yield and/or quality. Under watering leads to water stress, while the over-irrigated areas will experience higher potential for disease, leaching, and/or runoff. Either case will negatively affect return on investment. Non-uniform irrigation systems are over-irrigated to compensate for the poor DU which directly increases pumping cost. Leaching of chemicals increases cost and has the potential of polluting ground water. Run-off wastes water and applied chemicals, while simultaneously striping soil which also increases cost. (Smajstrla, Zazueta, and Haman, 2002)

The scarcity of water in some regions has brought with it water restrictions. When existing irrigation systems, operating at higher pressures and lower uniformities, do not functioning adequately under new water usage guidelines, system upgrades will be required. Government programs like EQIP (Environmental Quality Incentives Program) incentivizes growers to upgrade older systems by providing technical and cost-share assistance to improve irrigation efficiency. Water conserving irrigation systems, pipelines and conveyance systems may be cost-shared and incentive payments are available for producers who engage in and document improvements in water use efficiency (NRCS website).

The majority of mechanized irrigation systems installed today deliver water at relatively low pressure to crops via hoses that drop down from the systems mainline. Conventional high-pressure mechanized systems are typically about 60%-75% water efficient (meaning 60%-75% of the dispensed water ends up in the crop root zone). End guns operate at relatively high pressures which require large energy inputs per unit of water delivered. (Smajstrla, Clark and Haman) Other high pressure sprinklers include, impact sprinklers or unregulated spray or rotary type sprinklers with high inlet pressures. Lower pressure, LEPA and Drip, systems are 95%-97% (Amosson, New, Almas, Bretz, and Marek, 2002) water efficient. In addition, given the systems run at lower pressure, reduced pumping needs result in energy savings of 20%-50%. (William Blair & Company, 2009)

The prohibitive cost of obtaining perfect uniformity requires that a balance be struck between the value of the natural resources wasted and the increased cost of achieving greater application uniformity. Adopting new irrigation technology is considered feasible when the benefits of doing so are lower than the investment costs (Amosson, New, Almas, Bretz, Marek 2002). When taking into account pumping, labor, and other irrigation system operating costs, the total cost of a well designed system, with greater uniformity, will almost always be lower than for a poorly designed irrigation system. (Smajstrla, Zazueta, and Haman)

PRESSURE REGULATORS DEFINED

An in-line pressure regulator acts very much like an ordinary valve. The big difference is that a pressure regulator does not require constant manual adjustment of the water flow. Inlet pressure is reduced by reduction in the flow path inside the regulator.

Fig. 5: Various pressure regulator models and flow ratings.

In throttling stem type regulators (Fig. 6), flow enters through the inlet side and travels past a fixed seat and through a hollow cylinder (throttling stem) that moves in response to changes in back pressure. The spring tends to hold the regulator flow area open, while outlet pressure tends to close it. This duel between spring load and outlet pressure ends in a draw. The result is a constant preset outlet pressure determined by the strength of the spring (M. Healy, 2009).

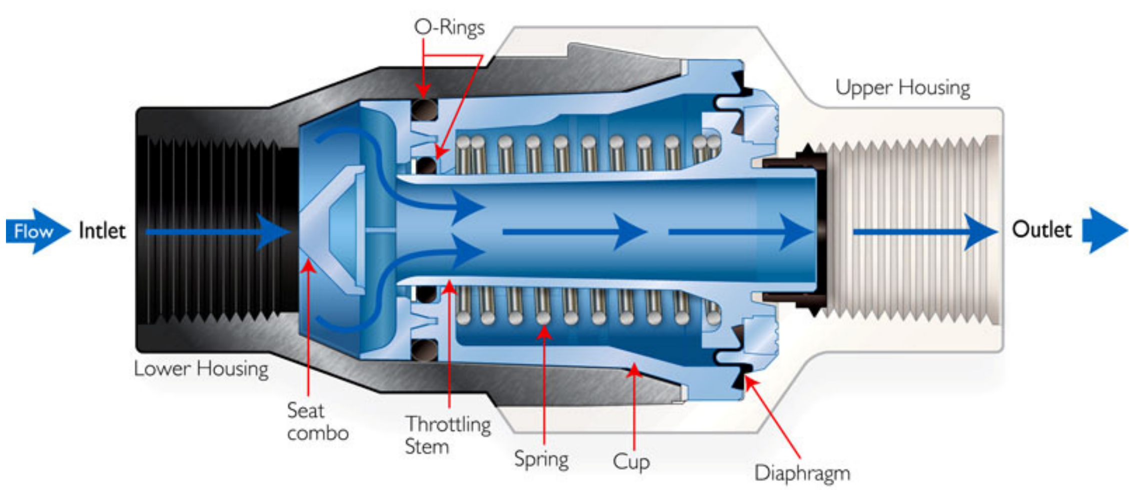


Fig.6: Cut-away of a throttling stem style pressure regulator.

To function properly a pressure regulator should have an inlet pressure at least five psi above the expected outlet pressure, and flow should match the manufactures stated flow range on the outside of the regulator. For example, a 10 psi regulator will require 15 psi inlet pressure for regulation to occur. The use of accurate pressure regulators ahead of all sprinkling devices will help provide uniform water distribution, even with varying regulator inlet pressure.

Flow control nozzle vs. Pressure Regulation

A pressure regulator controls pressure regardless of variation in flow, while a flow control nozzle meters the flow rate regardless of pressure variations. Pressure regulators maintain a preset outlet pressure regardless of inlet pressure and utilize an applicator's fixed nozzle orifice size to correspond to the desired flow. Flow control nozzles utilize a flexible disk with an orifice that changes shape as pressure fluctuates. As upstream pressure increases the disk orifice becomes smaller due to outward flexing of the disk (Fig. 7). However, as opposed to a pressure regulator, activation of the flow control device does not usually occur until upstream pressure exceeds a threshold pressure. Threshold pressure ranges from 20 to 50 psi depending on flow. Typical flow control nozzles require a smaller inlet pressure range than pressure regulators. (Mathers 2003)

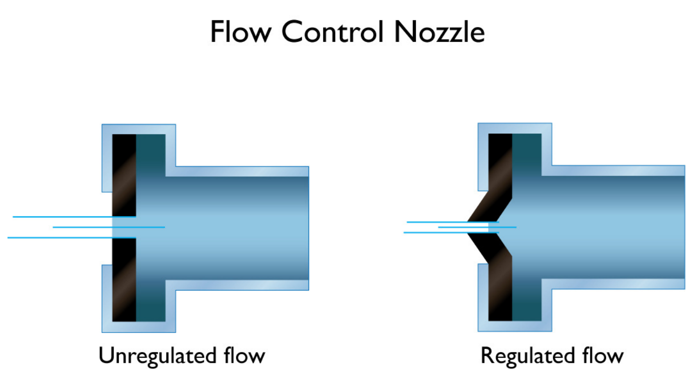


Fig. 7: Flow control nozzle before and during activation.

A common question is when to use pressure regulation and when to use flow control. Many factors will determine their use, such as; application (accuracy requirements), cost constraints, topography, and system configuration. Pressure regulators are generally more accurate than flow control nozzles by virtue of their design and have a wider operational window. The use flow control is relatively limited and cannot be selected for specific field situations. Rather, they are selected to operate within a range of operating pressures. This limits the capability of a flow control nozzles to accurately regulate flow rate. (Kranz, Irmak, Martin, Yonts, 2007) If an irrigation system has pressures differences greater than 20% of the design pressure, pressure regulators or flow control should be used.

Regulator Selection

Not only is the type/model of pressure regulator important in the selection process but also the manufacturer. It isn't just enough to select a low pressure regulator for efficient use of water and energy. High quality low pressure regulators must be matched with low pressure sprinklers to produce the optimum results. (Von Bernuth and Baird 1987)

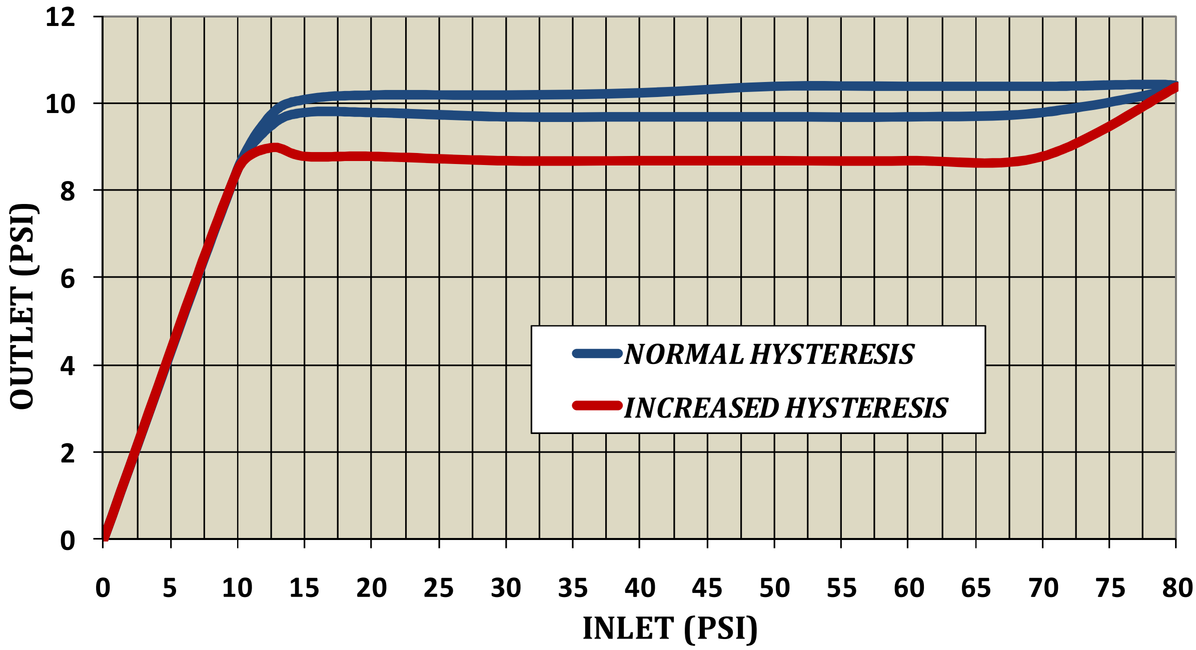


Fig. 8: Typical hysteresis in a pressure regulator

In a valve mechanism such as a pressure regulator, hysteresis (Fig. 8) is the phenomenon which can be described as drag or lag. Excessive friction loss or a poorly designed pressure regulator diminishes its ability to accurately respond to the pressure changes that it was designed to control. In a poorly designed pressure regulator, when inlet pressure increases, higher-than-desired outlet pressures will result. When inlet pressure declines, the friction loss factor can cause pressures to drop below the operating pressure resulting in a pressure regulator that doesn't regulate at all. (Elliott, 1997)

Regulators with high friction loss also require higher inlet pressures to operate thus requiring more energy with the potential consequence of compromising system flow. In some regions, flow can dramatically fall off due to well draw-down. As draw-down occurs system pressure will begin to fall, and because the nozzle orifice sizes are fixed, flow will also decrease. As draw-down continues, the pump may no longer be able to fill the irrigation lines resulting in portions of the system not emitting water. Selecting the right regulator for specific applications is critical for good system performance.

CONCLUSION

Pressure regulators can be used to significantly improve irrigation system efficiency resulting in lower costs, improved crop yields, reduced runoff, and conserved water. Pressure regulation limits pressure fluctuations that reduce distribution uniformity (DU). As the emphasis on water and energy conservation has increased, many irrigation systems are being designed or converted to lower pressure. This has resulted in system pressure fluctuations being a larger percentage of the total pressure, requiring more precise regulation. However, not all pressure regulators provide the precise regulation required for optimum system efficiency. Selecting the right regulator for the application is critical for consistent long term system operation. High quality low pressure regulators must be matched with low pressure sprinklers to produce optimum results. Greater awareness, through education, of the impact that uncontrolled pressure has on system performance and how to properly apply pressure regulators is essential for resource conservation. Pressure regulators are an important tool to ensure our future ability to provide food, fiber, and fuel for a hungry world.

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