

Review Article

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## Review of Venturi Injector Application Technology for Efficient Fertigation in Irrigation System

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### ABSTRACT

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The venturi injector has been used widely in different sizes of irrigation system as one of the main fertilization devices. The venturi injector plays great roles in the quality of crop production especially, integration with irrigation system. In this paper, some of the major limitations associated with the operation of the venturi injector has been highlighted. These major difficulties found are unstable suction flow, backflow, and critical cavitation. These limitations affect the hydraulic performance of venturi injector by reducing the efficiency or total working performance. The future work suggestions for further upcoming research concentration were presented for improvement of agriculture field.

### Introduction

Venturi injector is a tapered constriction faucet which operates on the principle that pressure drops accelerate the change of velocity of the water as it passes through the constriction. In order for the solution to flow from a tank into the injector, the pressure drops through the venturi must be sufficient to

create a negative pressure relative to atmospheric pressure (Barber, 1962; Ben Asher *et al.*, 1974; André *et al.*, 1978b; Bar Yosef, 1999).

A venturi injector does not depend on the external power for its operation. Venturi structure has no moving parts, which increases its life and decreases the probability of

failure (Wang, 2006; Wang *et al.*, 2006; Sun, 2010; Sun and Niu, 2010; Yan and Chu, 2011). Usually, the venturi injector constructed with plastic materials which makes it resistant to most reactive chemicals (Richardson, 1987; Yeager and Henley, 1986). It requires low cost, minimal operator attention and maintenance compare to other equipment with similar functions and operating capability (Clark *et al.*, 1991; FAO, 1993). It is easy to adapt to most popular irrigation system such as drip and sprinkler irrigation system, provided a sufficient pressure differential can be created (Hartz and Hochmuth, 1996).

Venturi injector can be differentiated by size and can be operated under different pressure condition. The specific model of venturi injector will affect the suction capacity (injection rate), head loss required and the range of working pressure (Janos, 1995). The level of supply tank drop also is among the factors which will decrease the injection rate. (Papadopoulos, 1993).

The geometrical parts of venturi injector are divided into three main sections such as a convergent section (nozzle), followed by throat section (constant part), ending with diffuser section. The geometrical parts can easy identified by geometrical variables such as diameters, convergent length and angle, and the diffuser length and angle (Weiler and Sailus, 1996; Dimitrios *et al.*, 2014).

### **Irrigation and fertigation system**

Fertigation is the way of dissolving the appropriate concentration of fertilizer in irrigation water by specified irrigation system (Keller and Bliesner, 1990; Mondal and Tewari, 2007; Kafkafi and Tarchitzky, 2011). The irrigated water with nutrient together is the important requirement of the farm input for increasing crop production. (Wahid, 2000;

Singh, 2002). From the conventional mode of application, fertigation has gradually transformed into the management of required water and nutrients. ( Meng, 2006; Yan *et al.*, 2010). It converts way and method of irrigation from solid fertilizer application directly to the farm towards the fertilizer applied directly to crops through irrigated water (Scaife and Bar-Yosef, 1995; Imas, 1999).

It could save an amount of water with fertilizer use efficiency, reduce labor and become economic management, improve land utility and ensure nutrient supply (Singh, 2002). Fertigation makes environment protection balanced as a result of soil conditions, crops outcomes of agricultural products improved (Neto and Porto, 2004).

Fertigation supported by the fertilizer types of equipment in order to achieve the performance of water and fertilizer in the field (Kessler *et al.*, 2004). Venturi injector is a common device used in fertigation for different size of the farms (Gao *et al.*, 2015).

It is used in macro and micro-irrigation systems due to its numerous advantages compared with pressure depending fertilizer tank, water injection pump, and electric injection pump (Johnson *et al.*, 1986; Reader-Harris *et al.*, 2001; Manzano and Palau, 2005).

The macro and micro-irrigation system with injected fertilizers has less cost than broadcast approach, soluble fertilizer, herbicides, and fungicides can be applied easily into irrigation water and with little extra equipment (Sciaroni *et al.*, 1957; Black, 1968).

The fertigation must be under these considerations: Size and complexity of nursery, water flow rate, injection ratio and mobility (Hofman and Van Cleemput, 2004). The fertigation model determine by which

additional equipment is needed such as valves, pressure and flow, regulators, but the basics equipment's for complete fertigation system must be fertigation device (Venturi injector) (Steven,2008). The concentration of the stock solution in fertilizer tank, filter, Non-Return Valve (NRV) and water meter, also flushing after fertigation for prevention of corrosion and microbial growth in the irrigation system (Nir, 1982; Papadopoulos, 1988; Smajstrla *et al.*, 1991; Burns, 1998;; Hanson *et al.*, 2006; Jensen, 2007; Gill *et al.*, 2011).

The fertigation system needs uniform water distribution and uniform fertilizer application (Keller and Bliesner, 1990; Burt *et al.*, 1997; Clemmens and Solomon, 1997; Pitts, 2001; Zerihun *et al.*, 2003; Heerman and Solomon, 2007; Martin *et al.*, 2007; Zerihun *et al.*, 2017).

The fertilizer should be soluble and compatible to be dissolved easily in water and easy transferred to the whole system of irrigation (Koths *et al.*, 1976; Dumroese *et al.*, 2005; Landis and Dumroese, 2006).

These the reviewed paper shows that many types of research deal with venturi injector with micro-irrigation (drip) system which is totally low-pressure system and low fertigation rate according to the needs.

Also, some of it deals directly with macro (sprinkler) irrigation with low-pressure specification for a small portion of the field. The outcomes will help further research to focus on the improved venturi injector parameters for efficient fertigation.

There is a need of maintains the optimum effective rate of fertigation and recovering pressure to reach the required performance of fertigation to different types of micro(drip) and macro (sprinkler) advanced technologies in the irrigation system.

## **Integrated fertigation with irrigation system**

The knowledge of integrated venturi injector with the system of irrigation in the world is the quickly spreading, as the rapid development of irrigation system and fertigation technologies (Sha *et al.*, 1995). However, the performance and accuracy of fertigation reduced by the low efficiency of fertigation devices such as venturi injector. (Shen *et al.*, 2001; Li *et al.*, 2005; Manikandan and Sivasubramaniam, 2015).

Currently, research has proved that ferti-irrigation-injection of dissolved fertilizer in water into micro and micro-irrigation systems has effective and economic outcomes (Fares and Alva. 2000; Shock *et al.*, 2003;Alva *et al.*, 2005; Fares *et al.*, 2009). Fertigation requires proper and secure connection of the system components, including the source of water, fertilizer tank, venturi injector, and irrigation system. (Strickland, 1894;Hodgson and Lake, 1954).

Water from the irrigation sources through the pipes under high pressure is converted into a high-velocity at the throat of the convergent-divergent portion which generates a low pressure (Power, 1993). The presented low pressure draws the liquid fertilizer from the tank through the suction pipe into the convergent-divergent portion (throat portion) where it mixes with the water (Jin, *et al.*, 2006).

In essence, the upstream pressure of the inlet water from the sources through a convergent nozzle converted to kinetic energy in the form of velocity head at the throat a portion of the convergent-divergent nozzle (Modi and Seth,2013; Rajput,2013). As the mixed water and fertilizer then the fluid expands in the divergent portion (diffuser), now the kinetic energy changed or converted back to

downstream pressure energy as an outlet the pressure at a convergent portion towards the irrigation system (Sne, 2006; Yan, and Chu, 2011).

## Venturi injector

### Structure

In the schematic diagram of venturi injector,  $Q_1$  ( $m^3/h$ ): Inlet flow;  $q$ : Injection flow;  $Q_2$  ( $m^3/h$ ): Outlet flow;  $D_1$  (mm): Inlet diameter;  $D_2$  (mm): Outlet diameter;  $d_0$  (mm): Slot diameter;  $d_3$  (mm): Suction tube diameter;  $d_1$  (mm): Constriction diameter;  $d_2$  (mm): Diffuser diameter;  $L_1$  (mm): Suction tube length;  $L_2$  (mm): Constriction length;  $L_3$  (mm): Throat length;  $H$  (mm): Diffuser length;  $\alpha$ : Constriction angle (convergent angle);  $\beta$ : Diffuser angle (divergent angle) while  $P_1$  (MPa) and  $P_2$  (MPa) are inlet pressure and outlet pressure respectively shown in (Figure 2).

For the presentation of structure parameters of venturi injector, the ratio between throat diameter and inlet diameter is the throat contraction ratio ( $\lambda_1 = d_1/D_1$ ), the ratio between throat length and throat diameter is throat length-diameter ratio ( $\lambda_2 = L_3/d_1$ ). Convergent angle and diffuser angle with differential pressure also is the important parameters to the totally flow of venturi injector (Manzano, 2008; Ashrafizadeh and Ghassem, 2015).

### Working principle

#### Convergent parts

The fluid flow towards the pipe at inlet section with constant volume towards the convergence part, which changes the flow rate according to the Bernoulli's principle which state that "within a specified flow field, the pressure decreases condition occurs when there is velocity increase condition". (Baylar *et al.*, 2005; Haijun, 2013).

Often convergent part or the constriction section reduces its cross section gradually according to design and function (Emiroglu and Baylar, 2003). The operation design of this part is to lower the temporarily static pressure of the fluid applied and higher the velocity of the fluid due to its shape.

So that the outcome of that the ongoing pressure to the throat part will be lower and high velocity generated (Manzano, 2008). This cause's fluid velocity tends to increase and the static pressure to decrease (Baylar *et al.*, 2005).

#### Throat part

This is the middle part which generates the pressure effect at the throat portion, also is the narrowest part in the whole venturi injector (Daugherty *et al.*, R.L., 1985; Emiroglu and Baylar 2003). The pressure difference at this section depends on the structural design of the convergent section which allows the drop of pressure at the inlet part of the throat (ASME standard MFC-3M, 1989; Hollingshead, 2011).

This part is a partially diverging portion by which the velocity undergoes the transformation back to pressure friction loss at a slight point (Daugherty *et al.*, 1985). Hence, the increasing velocity of the throat portion will influence the pressure drops under atmospheric pressure which facilitates the liquid fertilizer from the fertilizer concentrated cross tank to be injected through suction hole, through the pipe the dynamically mixed occurs with water and move to the divergent part (Baylar and Ozkan, 2006).

This portion shows that the applicability of the suction pipe diameter for fertigation process and the suction capacity mostly influenced by the throat diameter, thus the suction capacity decrease as the throat diameter increase when the slot diameter is fixed (Nithin, 2012).

### **Divergent part**

The fluid flow rate will decrease in this section due to the structural design. Therefore the current velocity will be lowered at divergence section which will cause the pressure recovering to start and will be almost of its initial size (Pennisi and Kessler, 2003).

In fact that the inlet pressure of the fluid toward the venturi decrease by the effect of the angle of constriction or convergence angle while the pressure recovering depend on the diffuser or divergent angle during the whole flow of the venturi tube (Janos, 1995; Kessler and Pennisi, 2004).

Hence the pressure difference at this point is the most important factor in this section (Wang, 2006; Sun, 2010). The divergent angle in this section is the among of the important parameter for it's greatest influence on the suction pressure which shows that according to the fluid flow condition the pressure drops in venturi injector occur s before constriction section or divergence part (Perdigones *et al.*, 2010; Yu *et al.*, 2012; Cheri *et al.*, 2014;).

### **Hydraulic performances**

The total performance of venturi injector has influenced by its structural parameters. The working performance can be evaluated by the injection efficiency, the pressure ratio, and the inlet flow rate ratio. The follows formulas can describe this phenomenon in details:

Let R to be the ratio of inlet flow rate, P to be the ratio of total pressure and the injection efficiency to be N

$$R = \frac{q}{Q_1} \text{ and } P = \left( \frac{S_1 - S_3}{S_1 - S_2} \right) \dots (1)$$

$$N = R \times P \times 100 = \left( \frac{q}{Q_1} \right) \times \left( \frac{S_1 - S_3}{S_1 - S_2} \right) \times 100 \dots (2)$$

Where  $Q_1$  refer to the inlet flow rate while  $q$  is the injection rate.  $R$  reflect the injection capacity of the injector.  $S_1$ ,  $S_2$  and  $S_3$  refer to the total pressure of inlet, outlet and the injection orifice respectively.  $P$  reflect the loss of the energy of the venturi injector.  $N$  is the outcome of the product of  $R$  and  $P$  which reflect the overall hydraulic performance of venturi injector or can measure the total working performance of venturi injector.

From the formula analyzed it shows that the constriction part, throat dimensions and diffusion part has a great impact on injection performance. The total pressure and the flow rate is clearer presented to the formula but in order to reach the accuracy of that two parameters the following keys parameters must be under investigation, including the throat inlet diameter ( $dt_1$ ), the throat length ratio ( $L_3/dt_1$ ), the ratio of minimum diameter of the diffusion to constriction part, constriction length ( $L_2$ ) and constriction angle ( $\alpha$ ), diffusion length ( $H$ ) and diffusion angle ( $\beta$ ) (Manzano, 2008; Haijun, 2013; Manzano *et al.*, 2015).

The analysis of the hydraulic performance shows that the Venturi structural parameters such as throat contraction ratio, throat taper, and throat length also has a direct effect to hydraulic performance such as minimum pressure, critical pressure and outlet average velocity (Jin *et al.*, 2006; Li, *et al.*, 2011). Generally the hydraulic performance and structural parameters of venturi injector evaluated in the mostly researched paper under numerical analysis with different CFD (Computation Fluid Dynamics) software such as FLUENT 6.2 (Chen *et al.*, 2005; Wang, 2006; Sun and Niu, 2012)

### **Limitations of the Venturi injector**

Fertigation system integrated with macro or micro irrigation system decreases its

efficiency by several factors such as fertigation devices (venturi injector), wind interference and by supplies more water to the whole of the cropped area (Philip, *et al.*, 2004). Venturi injector has several limitations during the operation periods (Dittakavi, *et al.*, 2010).

### **Convergent parts**

The difficulty of this part is the occurrence of backflow by which the water reverses its flow from the constriction part to the water sources due to the result of the downstream pressure to be greater than upstream pressure, this will reduce the fertigation efficiency by returning the fertilizer to the water sources (Zoldoske and Jorgensen, 1990; Vieira and Sumner, 1999; Thompson *et al.*, 2000).

### **Throat part**

The difficulty of this part as the truth of its design as known in venturi tube, at throat portion there is a suction orifice that connected to a fertilizer tank through a flexible pipe. The suction performance depends on the pressure and vacuum size in the throat portion. The increase in the difference between inlet and outlet, the pressure will increase the rate of suction but practically a minimum pressure is required to initiate the suction flow at a required inlet pressure (Schwankl, 2001).

However, dramatically affects occurred to the internal flow patterns in venturi injector such as suction flow the rate will be reduced at a certain point of operating conditions and usually affect fertilization uniformity and irrigation system efficiency. The level of vacuum reaches a certain amount which is below the saturated vapor pressure that is automatically the results of the critical cavitation at the throat a portion (Kedrinkii, 1976).

### **Divergent part**

Poor design of divergent angle (diffusion angle) will affect the venturi injector operation at an injection point of fertilizer and occurrence of cavitation condition which disturbs the whole system (Arai *et al.*, 2012).

The combination of several difficulties together with its sources show that the cavitation plays a major handicap for all flow problem causes mentioned above. The reviewed paper show that many authors worked on these problems in order to prevent the occurrence of other parameters which affect the flow but still remaining in fully developed cavitation. (Knapp, 1955; Stutz and Rebound, 1997). Therefore the major problem on venturi flow is developing of cavitation (Schmidt *et al.*, 1999; Liu, *et al.*, 2004; Barberon and Helluy, 2005).

In order to reduce and minimize the limitations caused by venturi injector, several technics should be applied during the design and installation of venturi injector integrated with any irrigation system. By installing the check valve between the water sources and injection point will prevent the backflow of water from irrigation line to the source, and installation of the normally closed solenoid (hydraulically) the operated valve between injection point and fertilizer tank to prevent unwanted flow of fertilizing, and this need well designed at the divergent portion. (Smith, 1990; Bratton, 1992).

The prevention of the major problem (Cavitation ) of venturi injector, it needs a proper design of venturi injector (throat portion) which will control the flow-rate ratio (ratio of suction flow rate to outlet flow rate ) to be less than 10% and stabilize the corresponding pressure ratio (ratio of inlet and outlet pressure) in uniform manner (Jin, *et al.*, 2006; Yan, *et al.*, 2010). The perfect design

of the divergent portion by considering the angle of diffusion in venturi injector by making sure that the angle will be between 4 and 8 degrees (Smith, 1990;Barre *et al.*, 2009).

### **Future work**

The future work must reflect on improved parameters of the venturi injector by optimization for maximum efficiency of fertilizer injection rate and recovering pressure for efficient fertigation under integration with irrigation system technologies. The flowing parts must be reflected:

To the divergent portion, in order to reduce the backflow effect which leads to unsteady flow together with more energy consuming, the pressure gradient designed must be small by adjusting divergent angle starting from 4 degrees, while the throat part must have zero pressure gradient and convergent must have favorable pressure gradient, to make more safety the installation of valves between irrigation sources, injection point, and suction portion must be considered for better efficiency of venturi injector.

The geometric profile of the convergent portion of proper venturi injector should be designed and testing, the convergent angle greater than 20 degrees, the length of the of a convergent portion should be designed and tested to equal or greater than the internal diameter, the suction diameter should be optimized and tested while the divergent angle should be tested from 4° in order to minimize the cavitation problem. so the diameters parameters have a great effect on the efficiency of venturi injector.

The fluctuation of upstream pressure and downstream pressure must be tested to optimum required the pressure at the convergent and divergent part respectively in order to reduce the cavitation and unrequired flow rate to the irrigation system.

The fluctuation of the pressure has a contribution to the effect of a venturi injector efficiency.

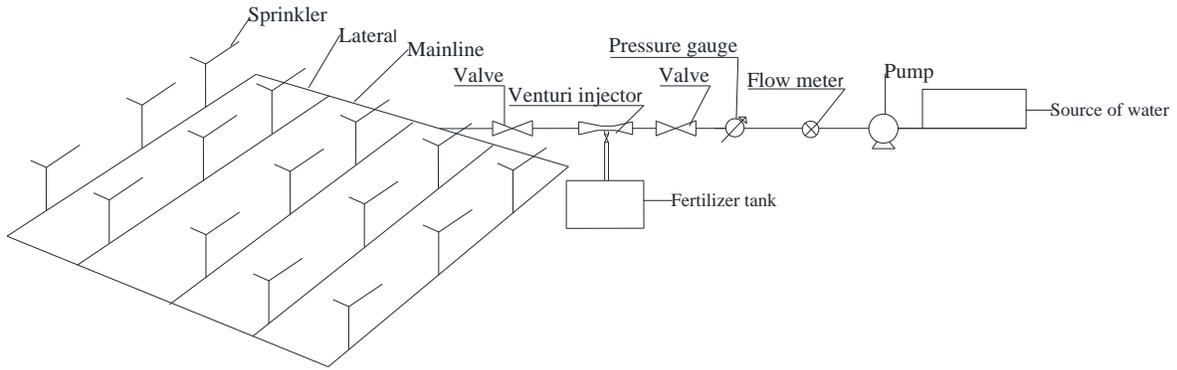
In order to control minimum pressure to the suction part at throat portion, the pressurized tank of fertilizer combination with venturi injector should be introduced in the future design due to the difficult pressure drop required to the venturi injector according to the existing design restriction of the irrigation system. Total pressure has influence on energy loss as well as direct reduction of venturi injector efficiency.

Designing of proper venturi injector to the macro and micro-irrigation system contribute much to the fertigation performance.

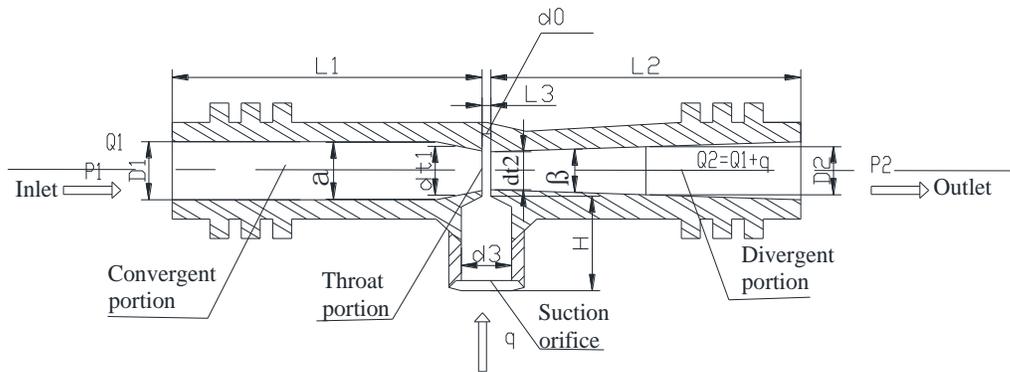
There are several factors which affect directly to the fertigation performance such as backflow of water and fertilizer to the irrigation sources, cavitation and fluctuations of upstream and downstream pressure which generally reduce the fertigation performance.

From these challenges presented in this paper, venturi device system of the irrigation for facilitation of fertigation system needs a well-designed, optimized and properly installed at convergent, throat and divergent portions for producing the maximum total efficiency as a result for effective production yield with required quality.

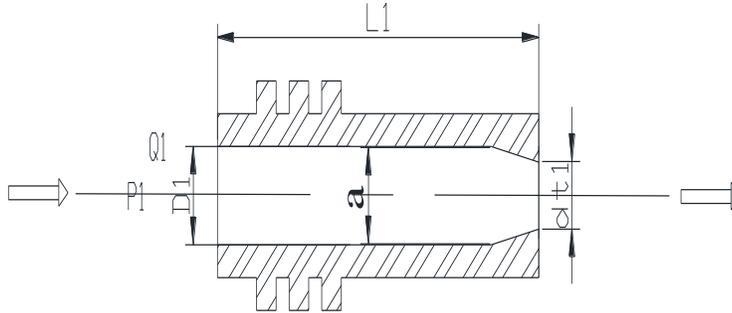
**Fig.1** Represent an example of Integrated Fertiligation under Sprinkler irrigation System



**Fig.2** Typical schematic diagram of Venturi injector structure



**Fig.3** Convergent part



**Fig.4** Throat part

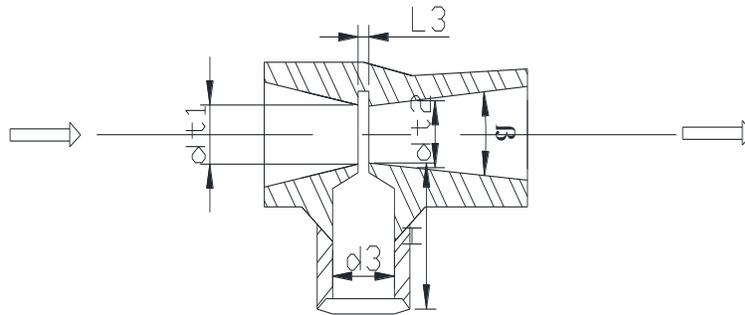
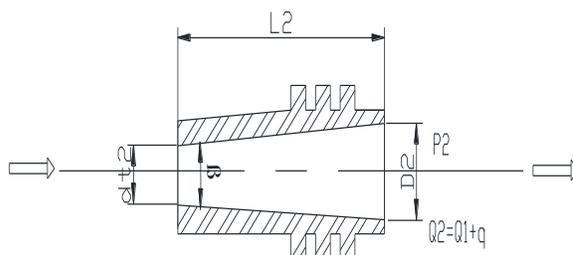


Fig.5 Divergent part



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