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Investigating the Influence of Differential Pressure and Solute Concentration on Performance of a Venturi for Fertigation

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ABSTRACT: A liquid fertilizer solution is injected through a venturi injector device to the irrigation system. The performance of venturi injector can be influenced by the injection rate and injection ratio of fertilizer solutions. The available venturi injector was investigated for injection rate and injection ratio with Urea and Nitrogen, Phosphorus plus Potassium (NPK: 18-10-12) fertilizer solutions. The operating pressures were under the range of 0.02 to 0.2MPa with normal water and fertilizer solution. Maximum injection rate was observed to be $0.22\text{m}^3\text{h}^{-1}$, when the urea dissolved in irrigation water at a ratio 0.075:1(urea: water), while the maximum injection ratio observed to be 7.1%. However, for (NPK) dissolved in irrigation water at a ratio 0.2:1(NPK : water), give out the minimum injection rate of venturi injector which was $0.01\text{m}^3\text{h}^{-1}$ while the minimum injection ratio of venturi injector was 1.8 %. Injection rate and injection ratio observed to be inversely proportional to the fertilizer concentration solution. However, the injection rate observed to be directly proportional to differential pressure across the specific concentration of a solution while the injection ratio observed to be maximum at a differential pressure of 0.07MPa and minimum at a differential pressure of 0.04MPa.

KEY WORDS: Investigating, Influence, Differential pressure, Solute concentration, Performance, Venturi, Fertigation, Irrigation.

I. INTRODUCTION

Fertigation is the application of a liquid fertilizer solution in precise amount towards the plant root zone with irrigation water [1, 2, 3]. The liquid fertilizer contains the required nutrients for plant growth, so as to increase the productivity of crops in the agricultural field compare to the conventional surface irrigation of solid fertilizer applications [4, 5, 6]. For this purpose the required rate and ratio of the fertilizer solution to the plant should be inadequate amount [7]. To maintain the constant amount of nutrients it needs the proper fertigation method as well as a micro-irrigation system. However, there some challenges of fertigation but there are several advantages for the adaptation of the fertigation system towards the agricultural field, the primary advantage of fertigation is the application of water and fertilizer economically [8]. It is normally less expensive to apply fertilizer to irrigation water than by other technics [9]. The other major advantage is the ability to apply fertilizer only when needed and required amounts [10, 11]. This application of liquid fertilizer not only emulates plant root zone needs closer than conventional methods but also minimizes the possibility of environmental pollution [12, 13]. Fertigation usually facilitates the application of liquid fertilizer at smaller amounts depending on the relatively needs of the plant compared to a one-time application of large quantities

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that are subject to leaching losses if it follows by heavy rainfall. Therefore, fertigation reduce adverse environmental impact and fluctuations of nutrients concentration towards the plant root zone, and increase the benefits of saving money, water conservation, crop damage protection and time management to reapply the materials [14, 15, 16]. The effective fertigation usually depend on the injection method selected and used. There are three main categories of injection methods for fertigation such as those depend on pump (fertigation pump) for example, proportional injector, those which used to depend on pressure differential methods (fertigation tank) such as pressurized mixing tank and the use of venturi principle (venturi injector) [17,18,19]. From three principle of fertigation, the venturi injector is best popular used device due to its advantage compared to others such as venturi injector come in various size of design and can be operated easily under different pressure condition [20, 21]. The injection rate, injection ratio, head loss and range of working pressure will depend on a specific model. It does not require external power and no moving parts during operations [22]. The injector usually constructed with plastic materials and low cost for chemical resistance during the chemical reactions [23]. The higher pressure loss compared to other methods of fertigation is the main limitation of venturi injector during operation according to Kumar et al. [18]. The wrong selection of fertigation method and poor-rate and the ratio of fertilizer solution concentrations will directly affect the efficiency of fertigation in the irrigation system [24, 25].

The accuracy and precision irrigation systems is still needed in the agricultural field in order to increase the crops production demand to society. However, available venturi injector in the field it needs more efforts in research in order to fill the gaps of inaccuracy data which still available in the field. The current study is to investigate the performance of available commercial venturi injector based on injection rate and injection ratio under different fertilizer concentration solution varying of differential pressure to make sure that the outcomes data will be applicable for the coming design of venturi injector and proper direction of operating pressure to varies irrigation system.

II. RELATED WORK

In our daily lives, incredibly large crop production and agricultural quality were expected to meet the world's food demand. To meet the requirements, it depends on the multiple agricultural technology reserves with accurate field data. Due to the uniformity of water distribution and liquid fertilizer to determine the root zone at the appropriate quantity and time, fertigation technologies have resulted and proven to be successful yield output. In the field of agriculture sector any expert can adapt the agricultural technologies but before applying any fertigation technology, the following factors should be considered.

1. The irrigation system, the macro and micro irrigation system should be analysed. Drip irrigation and sprinkler irrigation have different flow rates when installing with the fertilizer devices. Therefore the flow of two system will affect direct performance of venturi injector and other fertigation devices. The accuracy data should be presented for more clarification to the agricultural field for improvement of fertigation system.
2. Type of fertilizer and Fertilizer solution concentrations. The density, viscosity, concentration and kind of fertilizer were highlighted from different literature in order to make higher clarification to the commercial product available in the market. These factors will play a major role in the application of the fertigation system in the field. Therefore, a lot of research has been carried out to make this area clear to the user in the future for easier adaptation to the fertigation technology. Furthermore, most work has also been carried out to render this area widely available in the future and to allow the possible transition to fertigation technologies.
3. Type of injector, the form of injection depends on reliability, operation, repair, accuracy and ease of use. The range of flow rates and the reaction to the chemical used is the additional criteria for choosing the fertigation injector. The range of flow rate and reaction to the chemical used is the additional yardstick for the injector fertigation selection. Researchers reveal that, price, availability of power source should be included in the selection measure for higher production injector selection. The venturi injector, fertilizer tank and fertigation pump are common principle applied for the fertigation devices or technology, but there several factors affect the efficiency of injector in general such as poor installation methods, the size of the field and the crop type, the operation pressure and flow required to the specific type of injector.

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Through grouping multiple variables into three parts from relevant literature, it will help users as well as other stakeholders acquire knowledge about fertigation devices and its consideration for high-quality crop yield.

III. MATERIAL AND METHOD

Venturi injector

The available commercial venturi injector with the model of inlet and outlet diameter of 25mm and 23mm respectively, connected in parallel with the main pipes as shown in the figure 1.

Experiment devices

The experiment was conducted in the Laboratory of Research Centre of Fluid Machinery Engineering and Technology at Jiangsu University. The experiment scheme involved the pipes made of PVC materials as shown in figure 1. The inlet and outlet flow rate were measured by installing two flow meter, the upstream and downstream pressure were measured by installed two pressure gauges.

The reservoir of the laboratory was used to supply clean water for the experiment. The liquid fertilizer solution was sucked from the fertilizer tank by the injection pipe which has a diameter of 9mm.

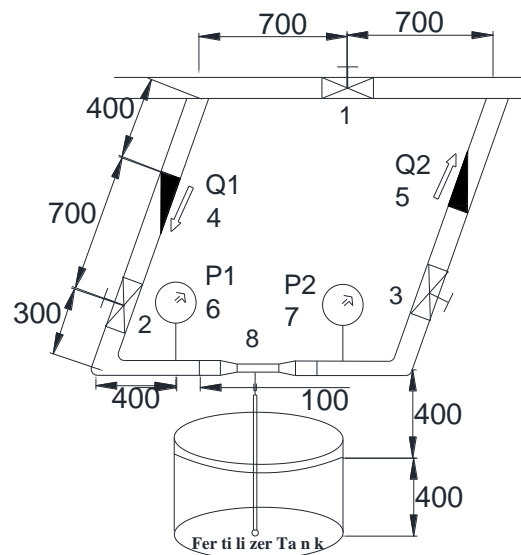


Figure. 1. The experimental devices of injection performance of venturi injector.

1, 2, 3 .valves, 4, 5 .flow meter, 6, 7.pressure gauge and 8.venturi injector. (dimension presented in figure 1 is in “mm”)

Experimental design

The valve 2 and 3 was used to control the upstream pressure and downstream pressure in order to produce differential pressure. The inlet pressure was 0.02, 0.04, 0.06, 0.08, 0.1, 0.12, 0.14, 0.16, 0.18 and 0.2MPa, totally ten levels. The different between the outlet flow rate Q_2 and inlet flow rate Q_1 where calculated to give the injection rate while the ratio

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of injection rate with inlet injection rate (q/Q_1) where calculate to give the injection ratio. The downstream pressure (P_2) were recorded at a range of 0.01 up to 0.06MPa.

A liquid fertilizer tank was brought near venturi injector to facilitate the sucking process through injection pipes. The Urea and Nitrogen, Phosphorus plus potassium (NPK) fertilizer was mixed at a different ratio with irrigation water, from 0.075:1, 0.1:1, 0.15:1 and 0.2:1(fertilizer: water).The mixed ratio of the amount of fertilizer with irrigation water presented (Table 1).

Table no 1: Different fertilizer amount with irrigation water

Irrigation water(Litre)	Fertilizer amount(Kg):Urea	Fertilizer amount(Kg):NPK	Fertilizer:water (Kg per litre of water)
20	1.5	1.5	0.075
20	2	2	0.1
20	3	3	0.15
20	4	4	0.2

The 20litres of clear water tank where mixed with selected amount of fertilizer to produce the specific concentration for different fertilizer as shown in the table 1.

The performance of venturi injector was calculated by the formula suggested by BIS [26],

$$\eta_{inj} = \frac{SOR}{OP_{max}} \times 100 \quad (1)$$

Where

η_{inj} , OP_{max} refer to injection efficiency of venturi injector, percent and maximum pressure allowed at the inlet of venturi injector, MPa respectively. SOR reflect the suction operating range for venture injector of the injection system which obtained by the difference between maximum pressure allowed at the inlet of venturi injector and minimum pressure at the outlet of venturi injector required to operate the venturi ($OP_{max} - OP_{min}$), MPa.

IV. RESULTS AND DISCUSSION

On the lower concentration of liquid fertilizer, the solution resulted in a higher value of injection rate compare to a higher concentration of liquid fertilizer solution which resulted the lower value of the injection rate. This reply that the injection rate of venturi injector is inversely proportional to the concentration of liquid fertilizer solution. Maximum values of injection rate resulted from Urea fertilizer under the ratio of 0.075:1(fertilizer: water) with injection rate $0.22\text{m}^3\text{h}^{-1}$ while the minimum values of the injection rate resulted from Urea fertilizer under a ratio of 0.2:1(fertilizer: water) with an injection rate of $0.02\text{m}^3\text{h}^{-1}$.

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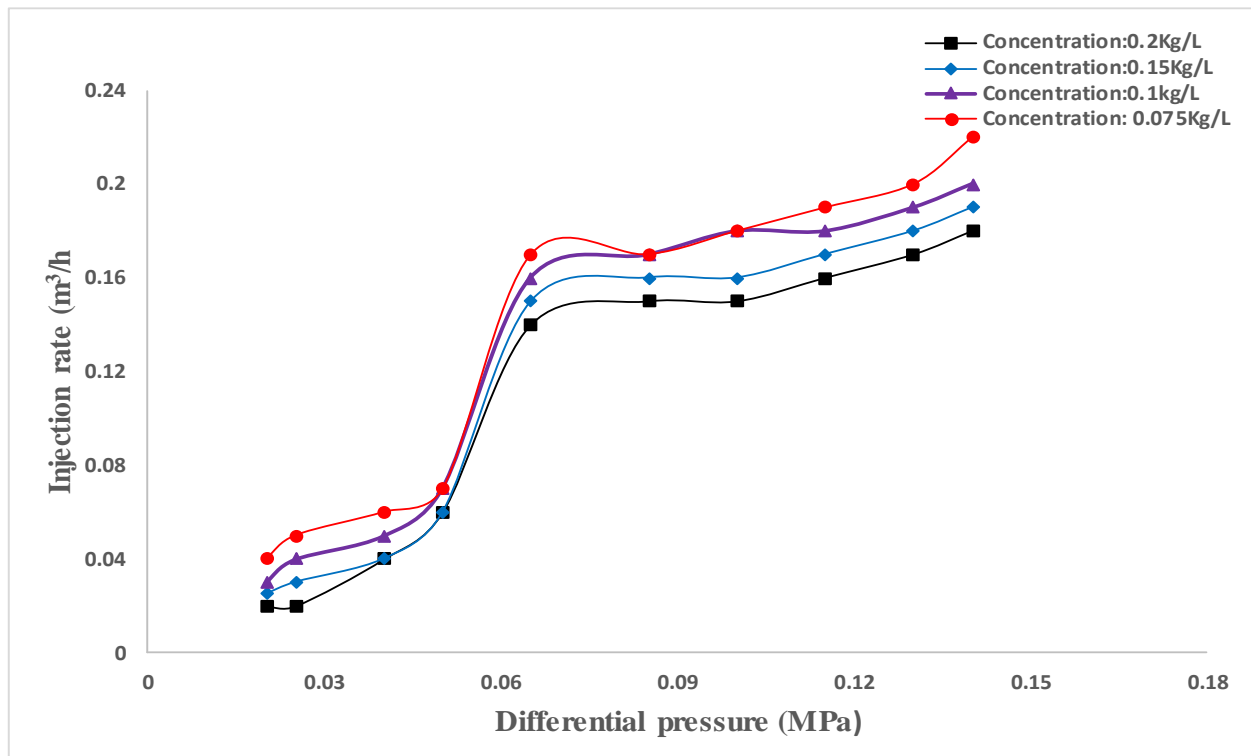


Figure. 2. Injection rate at different liquid fertilizer concentrations of Urea.

Figure 2 represent the lower concentration solution of Urea resulted in the higher value of injection rate values which appear at upper part compare to the higher concentration solution of Urea fertilizer which is resulted to lower injection rate values appear at the lower part. Similarly, Maximum values of injection rate $0.19 \text{ m}^3\text{h}^{-1}$ resulted from NPK fertilizer under a ratio of 0.075:1(fertilizer: water) while the minimum values of injection rate $0.01 \text{ m}^3\text{h}^{-1}$ resulted from NPK fertilizer under a ratio of 0.2:1(fertilizer: water).

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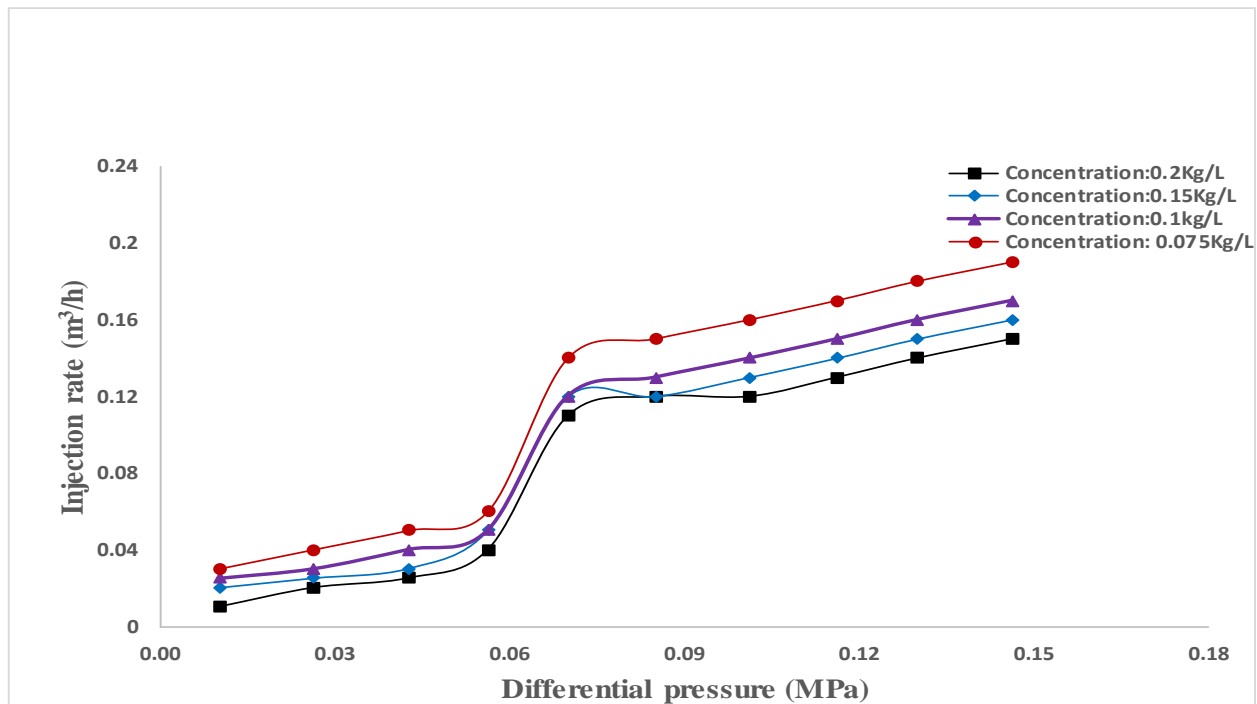


Figure.3. Injection rate at different liquid fertilizer concentrations of NPK.

Figure3 represents the lower concentration solution of NPK resulted the higher value of injection rate values which appear at the upper part compare to the higher concentration solution of NPK resulted to lower injection rate values appear at the lower part.

Injection rate is resulted to be proportional to differential pressure at different ratio of liquid fertilizer concentration solution for Urea and NPK. The increase in differential pressure for fertilizer concentration ratio of 0.075:1 to 0.2:1 (fertilizer: water) resulted to increase the injection rate for Urea and NPK fertilizer (Figure 2 and Figure 3). Injection ratio of venturi injector for Urea liquid fertilizer when dissolved in the ratio of 0.075:1 (fertilizer: water) resulted in maximum values across the different pressure differential which was 7.1%. Minimum value of injection ratio obtained when dissolved in the ratio of 0.2:1 (fertilizer: water) across different pressure differential which was 2.4%. Similarly, the maximum injection ratio of NPK liquid fertilizer dissolved in a ratio of 0.075:1 (fertilizer: water) resulted in 6.5%. The minimum value was 1.8% obtained from the ratio of 0.2:1 (fertilizer: water) across different pressure differential. This reflects that the injection ratio of venturi injector is inversely proportional to the liquid fertilizer concentration solution.

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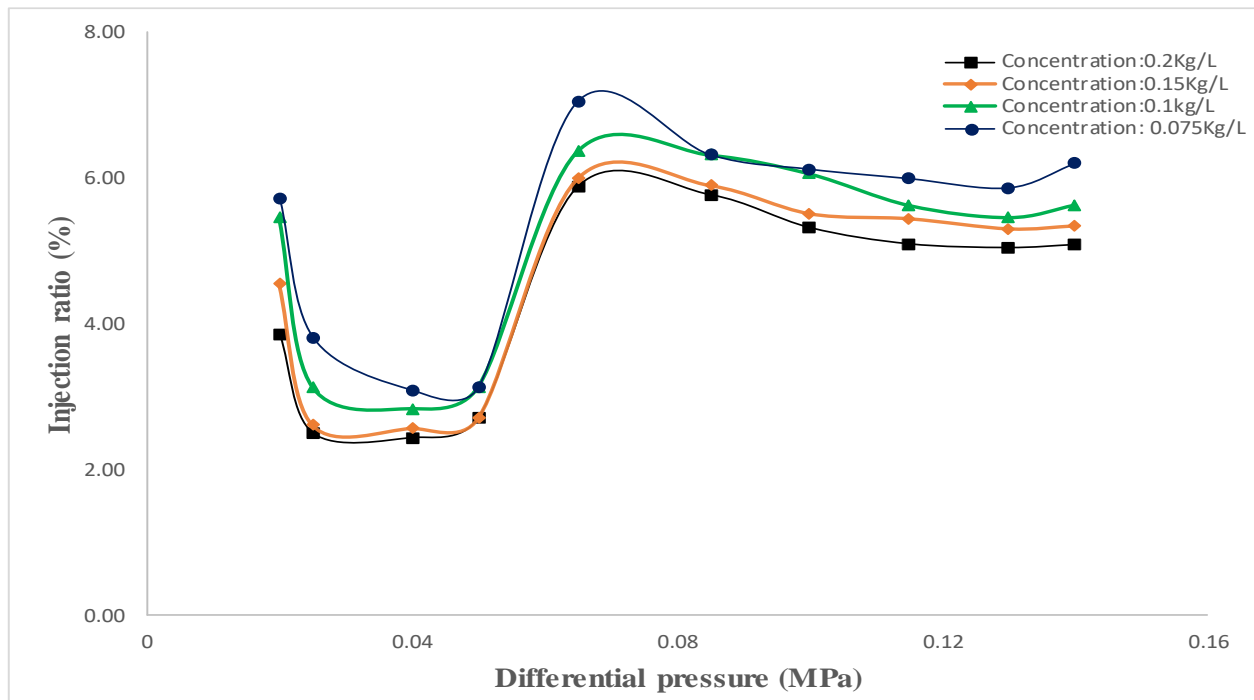


Figure. 4. Injection ratio at different liquid fertilizer concentrations of Urea.

Therefore at lower concentration solution of liquid fertilizer, the injection ratio value resulted to be higher and appear to be at upper part compare to higher liquid fertilizer concentration resulted to lower values of injection ratio and appear to be at the lower part as presented in (Figure 4 and Figure 5).

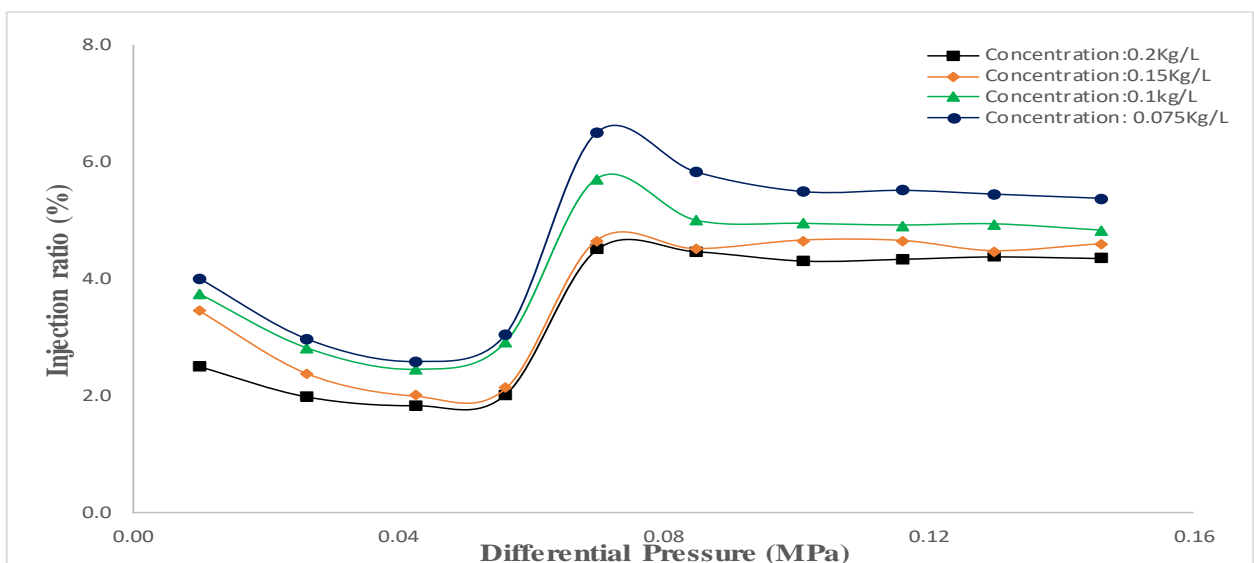


Figure.5. Injection ratio at different liquid fertilizer concentrations of NPK.

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Injection ratio is resulted to be maximum and minimum to different differential pressure at different ratio of liquid fertilizer concentration solution for Urea and NPK. The maximum injection ratios for both fertilizers resulted from a ratio of 0.075:1(fertilizer: water) at differential pressure of 0.07MPa. The minimum injection ratio observed from a ratio of 0.2:1(fertilizer: water) with differential pressure 0.04MPa (Figure 4 and Figure 5).

The performance of venturi injector at different irrigation ratio by increasing the inlet pressure resulted in the maximum and minimum injection rate of different liquid fertilizer. The maximum injection rate of Urea within the ratio of 0.075:1, 0.1:1, 0.15:1 and 0.2:1(fertilizer: water) was $0.22 \text{ m}^3\text{h}^{-1}$, $0.2 \text{ m}^3\text{h}^{-1}$, $0.19 \text{ m}^3\text{h}^{-1}$ and $0.18 \text{ m}^3\text{h}^{-1}$ respectively. The minimum injection rate of urea with the same ratio of 0.075:1, 0.1:1, 0.15:1 and 0.2:1(fertilizer: water) was $0.04 \text{ m}^3\text{h}^{-1}$, $0.03 \text{ m}^3\text{h}^{-1}$, $0.025 \text{ m}^3\text{h}^{-1}$ and $0.02 \text{ m}^3\text{h}^{-1}$. Similarly to NPK, the venturi injector resulted in the maximum injection rate within the ratio of 0.075:1, 0.1:1, 0.15:1 and 0.2:1(fertilizer: water) was $0.19 \text{ m}^3\text{h}^{-1}$, $0.17 \text{ m}^3\text{h}^{-1}$, $0.16 \text{ m}^3\text{h}^{-1}$ and $0.15 \text{ m}^3\text{h}^{-1}$ respectively, while the minimum injection rate at a given ratio was $0.03 \text{ m}^3\text{h}^{-1}$, $0.025 \text{ m}^3\text{h}^{-1}$, $0.02 \text{ m}^3\text{h}^{-1}$ and $0.01 \text{ m}^3\text{h}^{-1}$ respectively.

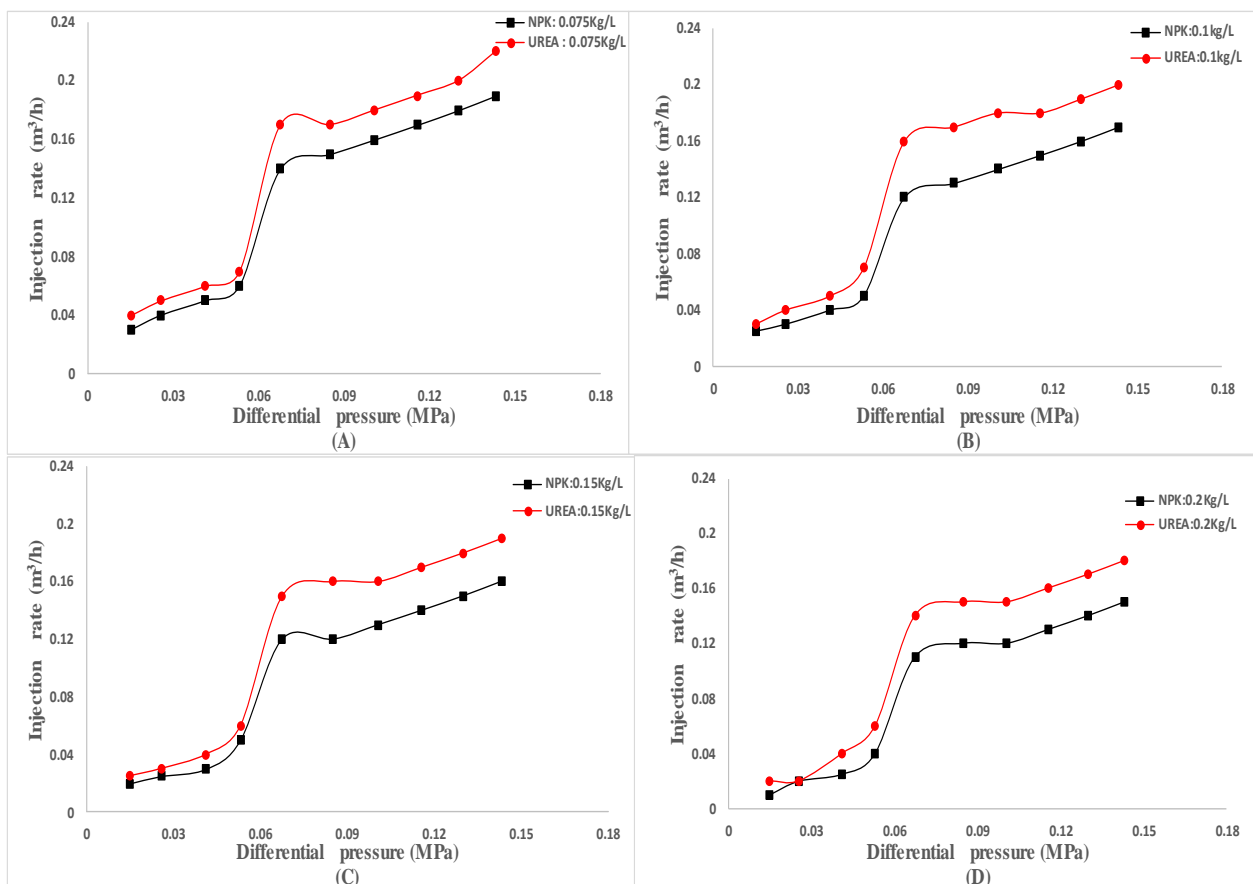


Figure.6. UREA and NPK fertilizer at different injection rates with the same ratio of concentrations as a function of differential pressure. (A) 0.075Kg/L, (B) 0.1Kg/L, (C) 0.15kg/L, and (D) 0.2Kg/L.

This implies that at different concentration solution of liquid fertilizer resulted in different injection rate. Then, observed that at the same concentration solution of different liquid fertilizer resulted in different injection rate values (Figure 6).

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The injection ratio of venturi injector also affected by concentration solution of liquid fertilizer. Both urea and NPK fertilizer at the same ratios of 0.075:1, 0.1:1, 0.15:1 and 0.2:1 (fertilizer: water) resulted maximum injection ratio for urea was 7.1%, 6.4%, 6.0% and 5.9% respectively while maximum injection ratio for NPK was 6.5%, 5.7%, 4.7% and 4.5% respectively. The minimum injection ratio of Urea and NPK within a ratio of .075:1, 0.1:1, 0.15:1 and 0.2:1 (fertilizer: water) was 3.1%, 2.8%, 2.6% and 2.4%, and 2.6%, 2.4%, 2.0% and 1.8% respectively.

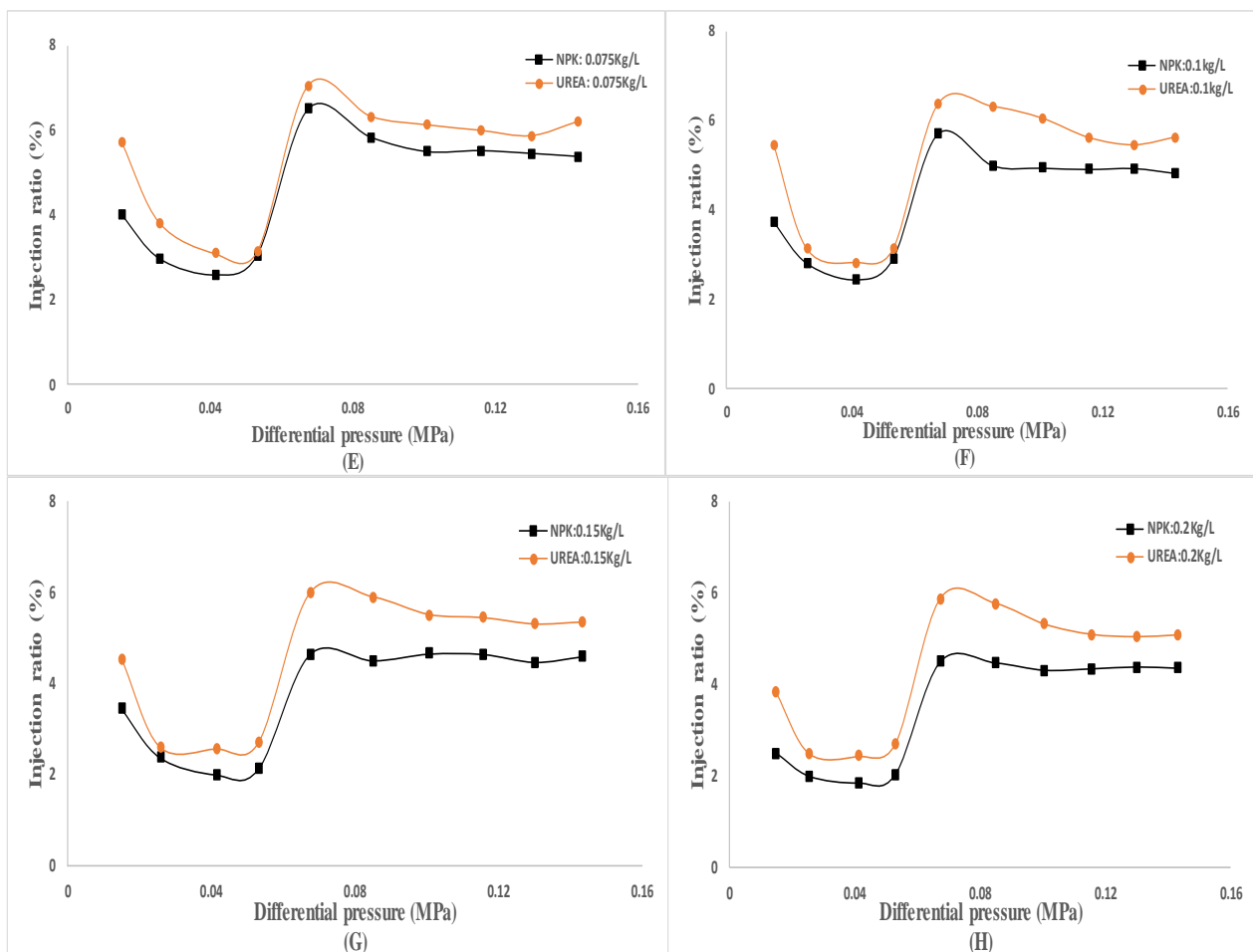


Figure.7. UREA and NPK fertilizer at different injection ratios with the same ratio of concentrations as a function of differential pressure. (E) 0.075Kg/L, (F) 0.1Kg/L, (G) 0.15kg/L, and (H) 0.2Kg/L

The maximum injection rate resulted for this venturi injector was $0.22\text{m}^3\text{h}^{-1}$ from Urea fertilizer while the minimum injection rate resulted in $0.01\text{m}^3\text{h}^{-1}$ from NPK fertilizer. The maximum injection ratio across the venturi injector with the range of operation pressure from 0.02 to 0.2MPa resulted from Urea fertilizer was 7.1% while the minimum injection ratio resulted from NPK fertilizer was 1.8%. Both liquid fertilizer solution decreases the injection rates and injection ratios as the increase of the concentration of the solution, this it might be due to different densities as reported the same result by Kumar et.al. (2012).

The efficiency of venturi injector was observed to be 95 percent under the operating pressure of maximum inlet pressure of 0.2MPa and minimum outlet pressure of 0.01MPa. This implies that the available venturi injector can operate at the high efficiency of both range for inlet and outlet pressure during the operating time.

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V. CONCLUSIONS

The injection rate and ratio of the commercially available venturi injector to irrigation water was noted to be inversely proportional to the concentration solution of liquid fertilizer. Maximum injection rate and ratio observed to be $0.22\text{m}^3\text{h}^{-1}$ and 7.1% respectively from Urea fertilizer within a ratio of 0.075(fertilizer: water). Minimum injection rate and the ratio was observed to be $0.01\text{m}^3\text{h}^{-1}$ and 1.9% respectively from NPK fertilizer within a ratio of 0.2 (fertilizer: water). The injection rate resulted to be directly proportional to differential pressure produced by commercially available venturi injector while the injection ratio resulted to be maximum at a differential pressure of 0.07MPa and minimum at a differential pressure of 0.04MPa. The overall performance of venturi injector observed to be 95 percent within the operation pressure.

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