Journal of Scientific & Industrial Research
Vol. 83, January 2024, pp. 92-101
DOI: 10.56042/jsir.v83i1.2666

Design of Ingenious Electronic Actuated Tractor Operated Liquid Urea Applicator

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Received 17 March 2023; revised 10 November 2023; accepted 24 December 2023

The paper contains the design, development details, and field performance of an ingenious electronic actuated tractor operated liquid urea applicator. The fundamentals of farm machinery design were taken into consideration in order to design and select the various components for the liquid urea applicator. The five-row prototype had a row spacing of 40 cm and applied liquid urea at a spacing of 30 cm in each line. The cut-off mechanism was controlled electronically with the help of a limit switch, sensor, solenoid valve, and relay. All the selected components in the designed electronic circuit for cut-off mechanism were powered by 12V DC, and to function properly, power was taken from the tractor's battery. The applicator was developed based on design calculations and then evaluated in the laboratory as well as in field conditions. During field evaluation of the developed prototype, it was found that the application rate was 392 $L{\cdot}h^{-1}$, actual field capacity was 0.36 $ha{\cdot}h^{-1}$, fuel consumption was 11.3 $L{\cdot}ha^{-1}$ with a 2.7 $km{\cdot}h^{-1}$ forward speed of the machine. The developed machine is suitable for applying liquid urea in the mulch field with minimum disturbance of soil, plant and residue. It would help in curbing paddy straw burning and reduce fertilizer losses due to volatilization.

Keywords: Cut-off, Farm mechanization, Injection, Mulch field, Sensor

Introduction

India is the world's second-most populous country, with 17.7% of the world's population.[1] Nearly 54.6 percent of the population is employed in agriculture and related activities.[2] At current prices, agriculture accounts for 17% of the country's gross value added in 2017–2018.[3] Food grain production increased from a low of 52 million tonnes in 1951–52 to 284.95 million tonnes in 2018–19 with an estimated target of 332.5 million tonnes for the year 2022–23.[4] With an increase in crop production, the amount of residue generated from the crop also increases in proportion. In 2014–15, 600–650 million tons (Mt) of crop residue were generated, out of which nearly 50% (361.85 Mt) of that residue was generated from cereals (34% by rice and 22% by wheat).[5] Due to not being able to manage such a large amount of residue, it is burnt in the field by the farmer. Open field residue burning emits large amounts of toxic pollutants into the atmosphere, which contain harmful gases like methane (CH_4), carbon monoxide (CO), Volatile Organic Compounds (VOC), and carcinogenic polycyclic aromatic hydrocarbons. It may eventually cause smog. When agricultural residue is burned, it also leads to the loss of field microorganisms that are helpful in nutrient fixation and residue breakdown, leading to a loss of soil organic matter and fertility.[3] Due to its harmful effect to environment and soil, in 2015, agricultural residue burning was prohibited by the environmental court.

The development of various types of residue management machinery, the establishment of Custom Hiring Centres (CHCs) for crop residue management machinery and education and communication activities for creating awareness among farmers by the government have helped in reducing stubble burning cases in recent years. There are several types of residue-retention-based machines available for the sowing of wheat crop in the paddy straw field. The introduction of happy seeder technology made it much easier to mulch rice straw while sowing wheat on surface-applied rice residue rather than burning and incorporating it.[6] The use of a no-till drill has a positive impact on wheat yield as well as productivity and resource use capacity.[7]

Crop fertilization is also essential for crop growth and productivity. The most simple and well-known method of boosting crop yields is to apply huge amounts of chemical fertilizer by the farmers.[8] In the 2018–19 fiscal year, approximately 314 lakh tonnes of urea were consumed, out of a total of 526 lakh tonnes of chemical fertilizer.[9] The fundamental challenge in using chemical fertilizers is that the total

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amount applied is enormous, but the usage efficiency is quite low.[10] Excess nitrogen losses were caused by the widely used fertilizer urea in solid granular. Fertilizing crops in a residue field is even more difficult task as applied granular fertilizer is retained by the straw and nutrients are not available for the growing crop. Surface urea application resulted in substantial total losses as well as high ammonia volatilization rates.[11] Applying liquid fertilizer is one of the most effective methods to solve the problem of losses occurred due to solid fertilizer application. Utilization rate of fertilizer increased when fertilizer was applied in liquid form. In comparison to solid fertilizer, liquid fertilizer had the advantages of high fertility and easy absorption, as well as ease of application and reduced pollution.[12,13] However, by adopting a precise nitrogen application management method that incorporates fertilizer into the soil, considerable nitrogen losses can be avoided. In recent years, the amount of liquid fertilizer used has increased.[14] As a result, crop fertilization mechanization has become increasingly important. So, the requirement of liquid fertilizer application machinery will rise in the future.

According to the IPNI (International Plant Nutrition Institute), the Best Management Practices (BMPs) for nutrient management emphasized the application of nutrients at the right time, at the correct rate, of the right product, and using the most appropriate method of nutrient placement.[15] The spot injection method is superior to the other injecting fertilizer methods.[15] It can reduce the time exposed to the air and directly inject liquid fertilizer near the roots, increase the available fertilizer efficiency of liquid fertilizer, and lower the amount of liquid fertilizer used. Reduce the pollution caused by excessive liquid fertilizer in the environment. Due to a technological gap, site-specific nutrient treatment is required for delivering liquid urea near plant roots using machinery by punching without soil, root, and residue disturbance, which also coordinates with the practice of conservative tillage.[16]

The research on the development of such types of machinery is limited in India and overseas. In this context, some efforts were carried out and developed a liquid urea nitrogen applicator (self-propelled) having a mechanical cut-off system[17], but could not able to deliver desired results. The mechanical cut off system had the limitation of delivering an accurate amount of liquid urea and wear and tear of cut-off mechanism. In terms of the accurate amount, proper depth, and other factors, the electronic metering system significantly outperformed the mechanical one.[18] An electronically controlled applicator can be used instead of the mechanical system because the mechanical system can only complete the basic application function. However, electronic actuated systems are much better in terms of linear and quick response and accuracy, integrated control systems and easier interconnections, low power requirements, substantially instantaneous response, no time lag or transmission delay, and contamination in the control medium.[18] To address the issue of fertilizer losses and mechanized liquid fertilizer application, there was a necessity to design and develop a cost-effective machine with an electronic actuated cut-off system i.e., tractor operated liquid urea applicator machine. This developed machine could be an innovative mechanical intervention that fulfills the objective of applying liquid urea in straw mulch field that increases fertilizer utilization and saving of excess liquid fertilizer. Hence, keeping above facts in mind, the specific objective of the study was to design and fabricate a tractor-operated liquid urea applicator for application of urea in mulch field.

Materials and Methods

Design and Selection of Different Components

The design of the prototype invented for applying liquid urea application in straw mulch field was based on the functional requirement of the application of fertilizer. The development involves designing of electronic metering mechanism, wheel assembly unit, fertilizer cut-off mechanism and pipeline structure for the flow of liquid urea. A prototype of tractor operated liquid urea applicator was fabricated using designing software (Solid Works) and after that, the prototype was evaluated in lab conditions. The assumptions were made in theoretical design procedure for above mentioned components are following i) The tractor pulls the urea injection wheel to enable the liquid urea injection application to operate; ii) The fertilizer injector wheels are towed wheels. The remaining parts of the designing section focussed on design of wheels based on functional requirements and farm machinery approach using different equations.

Main Contents of the Design

Mechanical design of a rotary wheel for liquid urea injector was based on calculations for the amount of injection, timing of injection, cut-off and pressure required. The rotary wheel for liquid urea injection was mainly composed of an injector, distribution hub, hollow spoke pipe in wheel, hollow circular centre shaft, shaft end retaining ring, O-rings, bearing and sealing ring. Rotary wheel type structure achieved rotary movement during liquid urea application by ground friction under the traction, like a ground wheel.[19–21]

Design of Wheel Components

Based on the spread diameter of wetted soil, the longitudinal and lateral (across row) injection spacing was determined in both types of soils (heavy texture and light texture soils). The spread index with volume of 20 mL per injection was found best.[17] Hence, the design of the injector was done based on volume.

Average spread diameter of wetted soil with 20 mL volume/injection = 18.91 cm ~ 19 cm.[17]

In the present study, liquid urea was to be applied before irrigation in wheat crop sown by happy seeder machine. As irrigation was applied after the application of liquid urea, it resulted in more movement of fertilizer in the soil-lateral, longitudinal and downwards to the root zone of the crop.

Longitudinal nitrogen movement observed after irrigation = 10 cm (5 cm each side)

Hence, the spacing between consecutive injection in the row = 19 + 10 = 29 cm ~ 30 cm … (1)

The nitrogen use efficiency increased when longitudinal spacing was increased from 20 to 40 cm[22] hence, optimum lateral (across-row) injection spacing was found to be 40 cm. Wheat crop sown by happy seeder was 20 cm row to row distance. It can cover two row of wheat crop in this spacing. At least on one side, every wheat row has injection point which would be efficient. It was suggested that smaller injection intervals in both dimensions would raise fertilizer application costs while not improving fertilizer use efficiency.[22] Analysis of liquid urea distribution from the injection point revealed unacceptable variability when this interval was increased further. Based on the above fact and experimental review, the longitudinal distance of injector was taken 30 cm from Eq. (1) and the lateral distance between injector as 40 cm.

Number of injectors taken per wheel = 8

Then, Angle between consecutive injectors at the centre of wheel = 360/8 = 45° … (2)

Perimeter of wheel = injector spacing × number of injectors per wheel = 30 × 8 = 240 cm … (3)

Total diameter of wheel (D) = 240/π = 76.43 cm ~ 75 cm (Fig. 1(d)) … (4)

Thickness of straw mulch in field at the time of sowing = 4.5 – 5 cm (measured during sowing time)

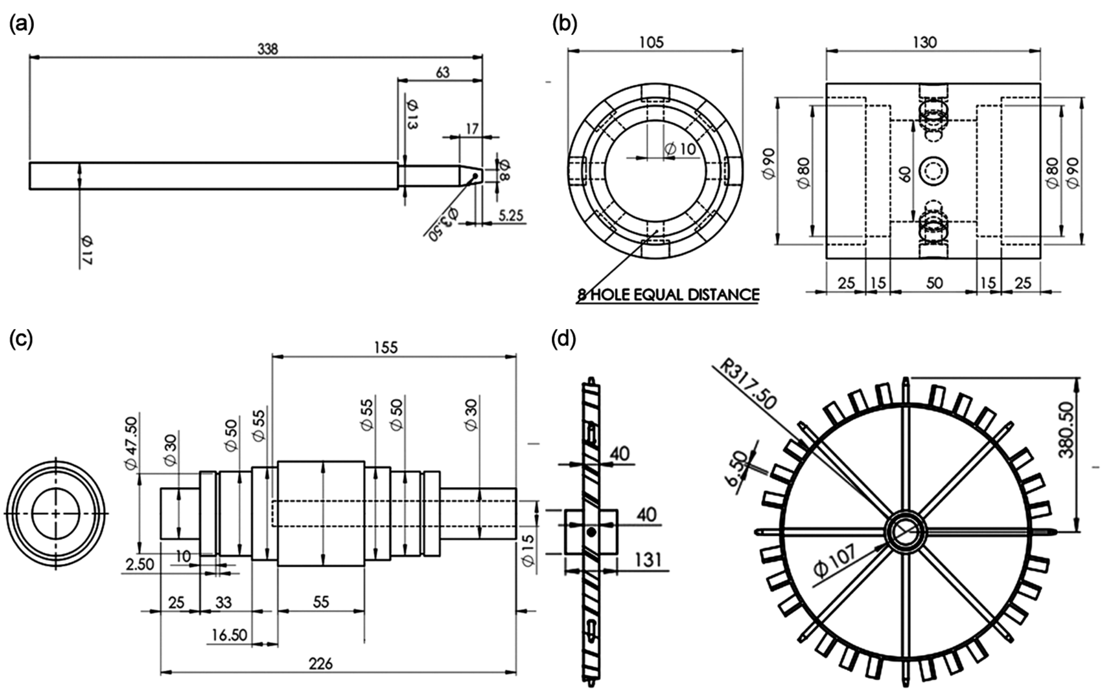

Fig. 1 — Different components of wheel a) injector; b) hub; c) circular shaft; and d) wheel (all dimension in mm)

Length of injector (l_n) = 6 cm (Fig. 1(a))

Number of injections in 30 m run by single wheel = 100 (each injection per 30 cm)

Total area covered per 30 m run = 30 × 2 = 60 m^2… (5)

Hence, Area covered/injection = 60/500 = 0.12 m^2 … (6)

Injection rate = 20 mL/0.12 m^2 = 0.167 $L \cdot m^{-2}$ ~ 0.170 $L \cdot m^{-2}$ … (7)

Number of injections/ha = $(10000 \times 100 \times 100) \div 1200 = (83333.33) \sim 85000$ … (8)

If 20 mL liquid will be injected through each injection, then required

Volume of liquid urea solution/ha = volume injected per injection × number of injections per ha

= (20×85000) / 1000 = 1700 $L \cdot ha^{-1}$

Injection Timing

Distance between consecutive injection = 30 cm

Speed of operation (assumed) = 1.8 $km \cdot h^{-1}$ = (1.8×1000)/60 = 30 $m \cdot min^{-1}$ … (9)

Number of rpm (N) = Speed of operation/(πD) = 30/(π × 0.75) = 12.73 = 13 rpm … (10)

Injector opening = 15° (based on the sensor cut off system)

Time required by rotary wheel to rotate 15° = 1/360×60/13 × 15 = 0.19 s = 0.20 s … (11)

Hence, in 0.20 s injector has to deliver an amount of volume 20 ml liquid urea.

Injector Orifice Size

Injection volume = 20 mL/injection

Injection time = 0.20 s

Flow rate of the injector = 20 mL/0.2 s or 100.00 $mL \cdot s^{-1}$ or 6 $L \cdot min^{-1}$ … (12)

As in less time more amount of volume needs to be discharged then high-pressure pump was required. Depending on the availability in the market and the requirement of system, pump (12V DC) was selected which delivers a minimum pressure = 7.0 $kg \cdot cm^{-2}$. The liquid urea flow rate via the injector hole created the pressure differences in the injector. The average penetration resistance of soil in experimental field was found 6.6 $kg \cdot cm^{-2}$.

Which is given by following Eq. (13).[23]

$$p_i - p_s = \frac{Q_i^2 \times \rho_d}{2(C_d \times a)^2}\ kg/cm^2 \quad \dots (13)$$

where, p_i = pressure at injector orifice, $kg \cdot cm^{-2}$; p_s = penetration resistance of soil, $kg \cdot cm^{-2}$; Q_i = rate of liquid urea flow through injector, $L \cdot s^{-1}$; ρ_d = density of liquid urea, $kg \cdot L^{-1}$ = 1.04 (measured); C_d = coefficient of discharge = 0.60 [23]; a = cross sectional area of injector orifice, cm^2

Putting the value in Eq. (13), we get

$$7.0 - 6.6 = (0.1 \times 0.1) \times 1.04 \div 2 \times (0.6 \times a \times a)$$

=> a = 0.1900 cm^2 = 19 mm^2 … (14)

Cross-sectional area of injector orifice (a) = $\pi d_i^2/4$ = 19 mm^2 … (15)

where, d_i = diameter of injector orifice, mm; d_i = 4.92 mm ≈ 5 mm … (16)

To avoid clogging of injector in soil/straw and to obtain proper injection liquid urea 2 hole on opposite to each other having size of 3.5 mm (as the cross-sectional area of 2 holes having a diameter of 3.5 mm is equal to the cross-sectional area of a 5 mm diameter hole) diameter was given on side periphery of injector as shown in Fig. 1(a).

Size of Distribution Hub and Hollow Circular Shaft

The circular shaft having eight holes rotated, through which liquid urea passed to the hollow spoke pipe. Centre shaft remained in continuous contact with rotary wheel during the working of machine. The hollow spoke pipes were mounted on the outer periphery of the distribution hub. On both side ends of the brass bush double bearing, rubber seals and O seal rings were given for leakage prevention. Width of circular ring was taken 40 mm for proper balance and rotation of rotary wheel. Hollow spoke was fixed between the circular ring and distribution hub. From safety point of view, minimum factor of safety (FOS) was taken as 1.25.

Then, width of the circular shaft at which rotary wheel rotated was = 40 × 1.25 = 50 mm … (17)

The standard size of radial ball bearing available in the market was given in the side of rubber seal. Due to bearing, rotary wheel would rotate smoothly and effectively. The range of standard bearing in the market varies from 10 mm to 80 mm. The ball bearing selected was of size - 50:90:20. Two standard seals (size - 50:80:10) were given on both sides with spacing of 5 mm of hardened chrome steel shaft to prevent leakage. O-type seal ring was given to lock the bearing. O-type seal ring (size: 2.5 mm) was given on both sides of shaft.

Standard width of bearing = 20 × 2 = 40 mm … (18)

Standard width of seal = 10 × 2 + 10 = 30 mm … (19)

Hence, total width of bearing = 40 + 10 = 50 mm … (20)

Total width of the circular hub = 50 + 30 + 50 = 130 mm (Fig. 1(b)) … (21)

Diameter of circular shaft = 60 mm

Diameter of hub at the place of bearing = 60 + 20 = 80 mm … (22)

Bore of ball bearing = 50 mm
Outside diameter of 50 mm bore ball bearing = 90 mm

Internal diameter of hub = 90 mm

Metal thickness to circular cover assembly = 15 mm

Outside diameter of the hub on the circular shaft = 90 + 15 = 105 mm … (23)

Two MS frames were developed for fixing the rotary wheel on the 3-point linkage frame. To fix MS frames, at least 25 mm of thickness was required on each side of the shaft.

Width required to fix the MS frame on the rotary wheel = 25 × 2 = 50 mm … (24)

Total width of circular shaft effective = 130 + 50 = 180 mm (Fig. 1(c)) … (25)

Outer diameter at the end of the shafts = 30 mm
Diameter of the liquid urea discharge hole = 10 mm
Diameter of bore in the shaft = 15 mm

Detailed specification of rotary wheel for urea application is also given in Table 1(a).

Pressure Loss in Distribution Hub

Volume of liquid urea delivered from the injector = 20 mL

Table 1 — Component specifications of the tractor operated liquid urea applicator

S. No.	Components description	Specifications	Type of material
a). Rotary wheel			
1.	Injector		Mild steel (MS)
	Type and length, mm	Hollow cone shaped and 60	
	Orifice diameter, mm	3.5 Two opposite holes, 5 mm above the tip of injector	
2.	Circular shaft and hub		Hardened steel chrome
	Size and shape, mm	105 × 130, Cylindrical	
	Diameter of discharge hole, mm	10	
	Length of bore, mm	150	
3.	Wheel		Mild steel
	Number of injectors	8	
	Injection spacing, mm	300 × 400	
	Diameter of wheel, mm	750 (including injector)	
b). Cut-off mechanism			
1.	Limit switch		
	Operation speed, cm/s and Dielectric strength, V	0.5–50 and 1500	
	Operation frequency, operation/min	120 (Mechanical) and 30 (Electrical)	
	Insulation resistance, m-ohm	100 (below 500V DC)	
2.	Proximity sensor		
	Type and model	Inductive and LJ18A3-8-Z/BX M18	
	Work detection distance, mm	1	
	Output and size, mm	NPN, 3 wire and18	
3.	Relay		
	Contact arrangement and ratings	2 & 4 changeover and 2 Pole-12 Amps	
	Insulation resistance, MΩ and dielectric strength, V	500 (at 500 V DC) and 1500	
	Release and operating time, ms	< 10 and < 20	
4.	Solenoid valve		
	Model and material	Electric, 2-way, normally closed and Brass	
	Size and dimensions, mm	1/2" and 129 × 90 × 69	

There is a need to keep a surplus amount of liquid urea in the hollow circular shaft to prevent fluctuations during discharge. So, minimum volume of 1.25 (FOS) times of the discharge amount was required in the bore of the circular shaft.

Volume stored in circular shaft = 20 × 1.25 = 25 ml = 0.025 l = 2.5×10^{-5} m^3 … (26)

Volume of shaft = $\pi r^2 l$ … (27)

where, l = length of bore done in circular shaft, m; r = radius of bore in circular shaft, m

Thus, from Eq. (27), we get

$\Pi \times 0.0075 \times 0.0075 \times l = 2.5 \times 10^{-5} = l = 0.142$ m = 142 mm = 150 mm … (28)

Volume stored in circular shaft = 20 × 1.25 = 25 ml = 0.025 l = 2.5×10^{-5} m^3 … (29)

For liquids[24], $\mu = \mu_0 \{1 \div (1 + \alpha t - \beta t^2)\}$ … (30)

where, μ = viscosity at t°C in poise; μ_0 = viscosity at 0°C in poise; α, β = constants for the liquid

For water, $\mu_0 = 1.787 \times 10^{-3}$ poise (N-s·m^{-2}); $\alpha = 0.03368$; $\beta = 0.000221$; ∴ $\mu = 1.787 \times 10^{-3}$
Putting values in Eq. (30), we get

$\left\{\frac{1}{1 + 0.03368 \times 20 - 0.000221 \times 20^2}\right\} = 0.001127$ poise = μ = 0.0001127 kg/s-m = 0.1127×10^{-3} … (31)

Density of liquid nitrogen (ρ) = 1040 kg·m^{-3}

Kinematic viscosity (v) = 0.0001127/1040 = 1.084×10^{-7} $m^2 \cdot s^{-1}$ … (32)

Velocity of liquid (V) = Flow rate/Area =$0.100 \times 10^{-3}/(\pi \times 0.0075 \times 0.0075) = 0.565$ m·s^{-1} … (33)

Reynolds number (R_e) = $(0.56 \times 0.005)/1.084 \times 10^{-7}$ = 25830.3 … (34)

Friction factor (f) = $0.079/(25830.3)^{1/4}$= 0.623 … (35)

Head loss in hub, h_f = (4 × 0.623 × 0.15 × 0.57 × 0.57) / (2 × 9.81 × 0.005) = 1.23 m … (36)

Pressure loss in hub = $\rho g h_f$ [24] = 1.04 × 9.81 × 1.57 = 12.63 P_a = 12.6 N·m^{-2} = 1.26 kg·cm^{-2}

Hence, pressure loss in the distribution hub is negligible.

Main Frame Unit

Two mild steel (MS) frames were developed to clamp the rotary wheel to the 3-point linkage frame of the machine. One end of the MS frames was fitted on the circular shaft and the other end of the MS frames was fixed with a specially designed clamping unit. A high-tension spring in the clamming unit protected the wheel from damaging on undulated land surface and also aids in smooth rotary motion during operation. The clamps were further fitted on the main frame of the machine with the help of the U-clamp bolts.

Development and Fabrication

In order to assist the manufacturing, tractor mounted liquid urea applicator was developed and fabricated on the basis of the designed parameters. The applicator was conceptualized, developed and manufactured at the Department of Farm Machinery and Power Engineering, Punjab Agricultural University, Ludhiana, India. Different view of 2D drawing of the developed machine are shown in Fig 2(a,b). Five fabricated wheels were assembled on the rear side frame (50 mm × 50 mm), which would be adjusted according to the need of row spacing. A three-point hitch linkage system was given on the front side of the frame. A distributor pipe of MS steel with a one-inch diameter was fixed on the machine, which has five holes for the discharge of liquid urea to the rotary wheel. With the help of half circular-type rings, a cylindrical tank was fitted above the frame. A CAD view of developed tractor operated liquid urea applicator is shown in Fig. 2(c). A metal box containing an electronic control mechanism was fitted between the frames. The applicator will cover the same width as equal to happy seeder machine. It

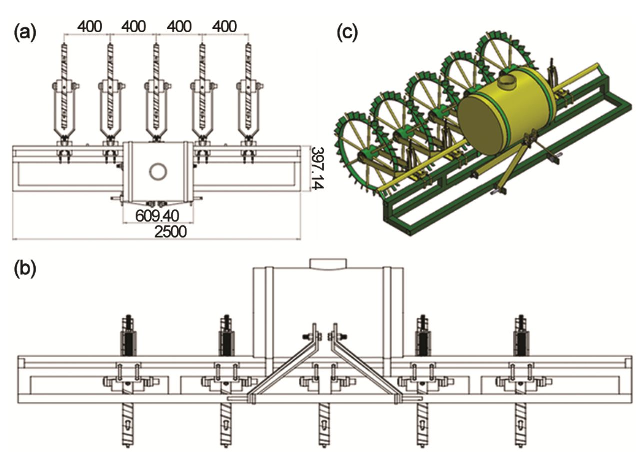

Fig. 2 — Drawing (2D) views of the developed machine a) top; b) front; and c) isometric view (all dimensions in mm).

would increase the operation of efficiency and reduce the chances of over lapping of crop row during the application. After starting of the machine, first the liquid urea entered in each distribution hub of the rotary wheels. Then liquid urea was injected into the soil to realize the liquid application of fertilizer in straw mulch field. The following aspects were considered during design to prevent or reduce the clogging problem of the injector:

- A diaphragm pump with a high-pressure flow rate was used to reduce the clogging chances of the fertilizer injector.
- The liquid fertilizer with high pressure passed through the injector, which enables the injection of liquid fertilizer with greater kinetic energy into the soil below the straw mulch without clogging.
- To avoid direct frontal contact with the soil and reduce the possibility of clogging the fertilizer outlets of the injector, the outlet holes would be oriented in the opposite side of tractor's direction.
- Lugs were fixed at an angle on the outer periphery of circular ring to ensure proper rotation and avoid skid of the rotary wheel.

The overall composition of the pipeline structure for the liquid urea injection consisted of a liquid fertilizer tank, a gate valve, water pump, and other essential components. In the liquid urea injection control system, the stability of pressure was also an important factor which affected the accuracy of liquid urea injection.[25,26] By applying controlled constant pressure, the reliability of fertilizer injection could be increased and energy could be saved.[27] Therefore, it was necessary to design a separate controlled pressure system to ensure stable pipeline pressure.

Cut-off Mechanism

The function of the limit switch in the liquid urea applicator machine was mainly to detect the state of lifting and lowering of the machine. The pump would start automatically, when the machine was in the working position. In headland, when the machine was in the lifted position, the pump would turn off with the help of limit switch. Proximity sensors with 1 mm detection distance were used to detect the hollow spokes of rotary wheels. In crop machinery, most of the pipeline flow control was achieved through adjusting the opening and closing frequency and duty cycle of the solenoid valve for spraying or fertilizer.[28,29] The selected solenoid valve normally remained in the closed position, after getting signal from the relay, it got actuated and passed the liquid urea through it for the injection. The remote-controlled switch (electro-mechanical relay-MSP-2 Pole 12V) with LED was selected to switching of the given solenoid valve. These relays would work at low power signal and would switches several circuits simultaneously, sequentially, or individually. The selected equipment would able to work in harsh environment (i.e., vibration and pollution). A view of the circuit diagram of the cut off system of the liquid urea applicator consisted of the above-described components as shown in Fig. 3. Specification of selected components used in cut-off mechanism of the liquid urea applicator was given in Table 1.

Performance Evaluation

The operational evaluation of the developed metering mechanism and rotary wheel assembly was done for discharge rate, pressure of liquid discharge and injection time for discharge.

Preliminary Lab Evaluation

The developed wheel was fitted on the frame of the machine in the lab for the evaluation of discharge and testing of cut-off mechanism. On the variable frequency drive (VFD) machine at three different speeds, on a fixed frame the testing of the rotary wheel was executed. With the help of the belt, drive was given to the rotary wheel and the amount of liquid urea discharged in a minute was measured. A rectangular tray was used to collect discharge of liquid urea. The parameters which affect discharge of the liquid urea were the pump pressure and injection time. Evaluation of the developed mechanism for liquid urea discharge in laboratory conditions was carried out using three levels of independent

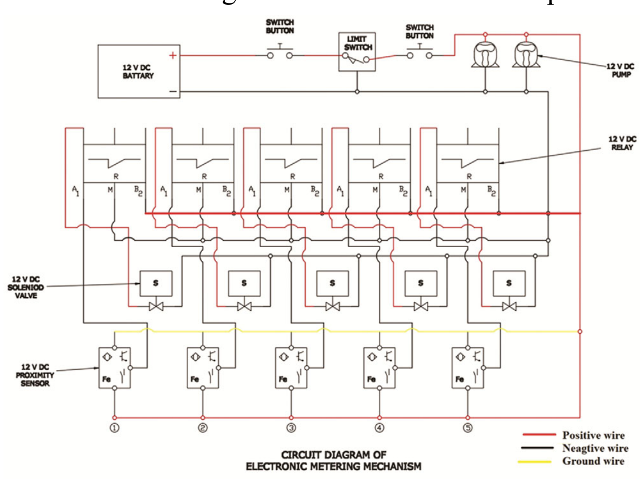

Fig. 3 — A view of circuit diagram of electronic cut off mechanism of liquid urea applicator.

parameters viz, Pressure (P1 (110 psi; 758.42 kPa), P2 (220 psi; 1516.85 kPa), P3 (330 psi; 2275.27 kPa)), Injection time (T1 (90 rpm), T2 (75 rpm), T3 (60 rpm)). Liquid discharge rate was depending on both the independent parameters.

Field Evaluation

Based on the result obtained from lab evaluation, field evaluation was carried out to assess the discharge rate, field capacity, and fuel consumption by the developed applicator. The developed machine was evaluated for treatments of forward speed as F1 (3.6 km·h^{-1}), F2 (2.7 km·h^{-1}) and F3 (1.8 km·h^{-1}) based on the operational parameters selected from lab evaluation.

Statistical Analysis

ANOVA was conducted to evaluate the effect of pressure and injection time on discharge rate. The laboratory evaluation of experiments which included independent parameters, viz. pressure and injection time, analyzed using a factorial completely randomized block design. The dependent parameters of the laboratory study were checked with the help of a post hoc test (Tukey adjustment) at 5% level of significance. The analysis was done using SAS software. The significance or non-significance between treatments was evaluated at 5% level with the help of a post hoc test for comparison.

Result and Discussion

Preliminary Lab Evaluation

The preliminary evaluation of the designed prototype for liquid urea application was carried out in lab conditions. During initial preliminary trials, the working of the machine in terms of discharge rate was satisfactory and uniform in liquid discharge was observed.

Discharge Rate

The effect of pressure and injection time on liquid discharge is shown in Fig. 4. The mean discharge of liquid urea increased with an increase in injection timing from T1 to T3 and similarly, discharge of liquid urea also increased with an increase in the level of pressure from P1 to P3. This was due to injection timing T1 has comparatively less opening time for the injector as compared to T2 and T3, respectively. It was observed that the discharge of liquid urea varied from 3.80 to 11.3 litres per 20.0 m run among all the treatments. However, mean discharge was

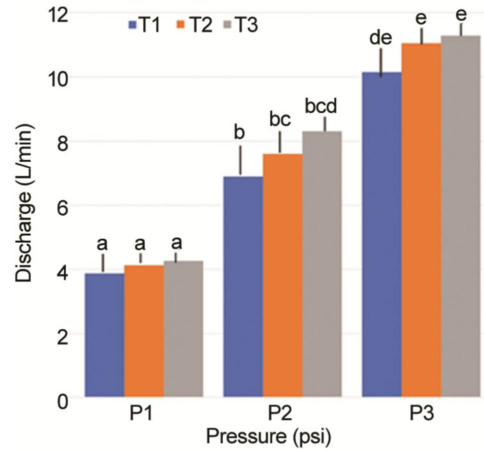

Fig. 4 — Effect of pressure and injection time on discharge rate: pressure of 110 psi; 758.42 kPa (P1), pressure of 220 psi; 1516.85 kPa (P2), and pressure of 330 psi; 2275.27 kPa (P3), and three level of injection time respectively (means with same letter are not significantly different, p>0.05).

significantly different at 5% level of significance from each other. The statistical analysis revealed that the effect of different pressure and time was found significant at 5% level of significance. Individually, the effects of pressure (P) and time (T) at different levels are significant. Whereas interactions of pressure and time (P*T) are non-significant (p < 0.0001). Mean discharge interaction in between pressure P1, P2 and P3 were found to be significantly different from each other as shown in Table 2. The pressure level P3 (330 psi) was chosen for field evaluation because it had the highest discharge rate with the greatest spread of liquid urea, making it easier for the plant to absorb more nitrogen from the applied liquid urea. Table 2 shows statistics of pressure (P) and Injection time (T). Wang *et al*.[30] also observed nearly 20 mL liquid with 3 mm diameter core hole at similar speed. In other study researcher[31] also observed same rate of liquid discharge in the same conditions. Silva and Magalhaes[15] also reported that 5–18 mL per cycle of liquid dose has been placed at 50–100 mm.

Field Evaluation

Field evaluation of the developed tractor-operated liquid urea applicator was carried. Evaluation of the machine indicated that the field capacity (0.25–0.44 ha·h^{-1}) was significantly (p < 0.05) different at all three levels of forward speed (Fig. 5). Thus, it is clear from results that, the machine can work at forward speed 1.8 km·h^{-1} (0.25 ha h^{-1}), 2.7 km·h^{-1} (0.36 ha·h^{-1}), and 3.6 km·h^{-1} (0.44 ha·h^{-1}).[32] The optimum

Table 2 — Statistics of pressure (P) and injection time (T) effect on discharge rate ($L \cdot min^{-1}$)

Source	DF	Sum of square	Mean of square	F-value	*p*-value	Significance
P	2	196.4534508	98.2267254	188.76	<0.0001	S
T	2	5.3155556	2.6577778	5.11	0.0175	S
P × T	4	**1.6853484**	0.4213371	0.81	0.5352	NS

S: Significant at 5%, NS: Non-significant, DF: Degrees of freedom

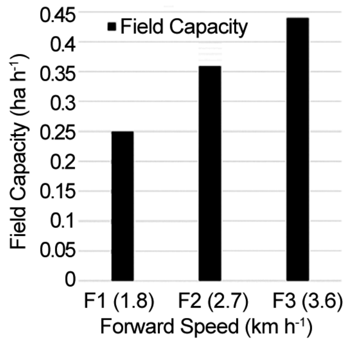

Fig. 5 — Graph for field capacity at different forward speed of the machine (means with same letter are not significantly different, $p > 0.05$).

performance of the machine was obtained using pressure and injection timing at 2.7 $km \cdot h^{-1}$ machine forward speed. At this forward speed, the application rate of liquid urea 392 $L \cdot h^{-1}$, actual field capacity of 0.36 $ha \cdot h^{-1}$ and fuel consumption 11.3 $L \cdot ha^{-1}$ was found. Other researcher[17] also observed similar application rate in the paddy straw field. Silva and Magalhaes[16] also observed similar rate of discharge per injection.

Economic Analysis

The material and fabrication cost for the developed machine was Rs. 90,000. Calculations indicated that, total of fixed and variable cost of 718.75 $Rs \cdot h^{-1}$. Cost incurred for application of liquid urea was found to be Rs 2000 ha^{-1}.

Conclusions

Design and development of a tractor operated liquid urea applicator consisting of an electronic metering mechanism was carried out. The machine had five rotary wheels consisting 8 numbers of injector (60 mm long cone shaped) per wheel with 2400 mm periphery that could easily penetrate and rotate in straw mulch field. Optimum performance was found at forward speed of 2.7 $km \cdot h^{-1}$. At this forward speed, the application rate of liquid urea was 392 $L \cdot h^{-1}$, actual field capacity of 0.36 $ha \cdot h^{-1}$ and fuel consumption 11.3 $L \cdot ha^{-1}$. The developed machine being suitable for applying liquid urea in the mulch field may increase mulching practice thereby reduce stubble burning. The new technology may be a superior alternative for urea application in crops. The application of machine also results in savings in fertilizer by reducing fertilizer losses, which increases the cost-benefit ratio for farmers. It also contributes to mechanized crop fertigation and a step towards precision agriculture in the field of fertilizer application.

Acknowledgments

Sufficient funding provided under CAAST project by ICAR and research facilities/infrastructure provided by PAU, Ludhiana for the conduct of research is greatly acknowledged.

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