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Development and Evaluation of LPG Based Heating System for BAU-STR Dryer

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ABSTRACT. Drying is an essential post-harvest operation before storing and processing of paddy. Delayed drying incurs post-harvest and quality losses of paddy. BAU-STR dryer using rice husk briquette as a heat source was developed earlier by the Feed the Future, USAID and ADMI, University of Illinois at Urbana-Champaign, USA sponsored Post Harvest Loss Reduction Innovation Lab (PHLIL)-Bangladesh project to overcome the problems. LPG (Liquefied Petroleum Gas) is a clean gas which is available in all over Bangladesh and could be a clean and easy source of producing hot air for BAU-STR dryer. The objective of this study was to develop LPG based heating system and conduct technical and economical performances of BAU-STR dryer. The experiment was conducted during 25 November, 2019 to 11 December, 2019 (*Aman* season) at the workshop of the Department of Farm Power and Machinery, Bangladesh Agricultural University, Mymensingh. Paddy variety BRRI dhan49 was collected from the BAU farm to conduct the experiment. LPG heating system was developed for BAU-STR dryer using locally available LPG cylinder and burner incorporated in modified local stove. The dryer performance was evaluated by setting two different heating units (rice husk briquette and LPG based) and two blowers (Vietnamese and locally manufactured blowers) combination. Treatment 1 (T1), treatment 2 (T2) and treatment 3 (T3) were briquette plus locally manufactured blower, LPG plus Vietnamese blower, and LPG plus locally manufactured blower, respectively for the study. Each treatment was repeated for 3 times. The temperature was maintained at 42±0.5˚C for drying paddy. The moisture removal rate was found 2%MC/hr, 2%MC/hr and 2.1%MC/hr for T1, T2 and T3, respectively. The drying efficiency was found 53.92±1.58%, 64.11±2.9% and 68.97±0.38% for T1, T2 and T3, respectively. The operating cost was estimated 0.78 BDT/kg, 1.13 BDT/kg and 0.89 BDT/kg for T1, T2 and T3, respectively. Average milling recovery was 75.54±1.92%, 75.99±1.44% and 75.51±1.12% for T1, T2 and T3, respectively. It is evident from the technical, financial and milling quality analyses that the BAU-STR dryer using LPG as a clean heating source with locally manufactured blower would be best option for the farmers, seed producers and small traders in Bangladesh.

Keywords: *BAU-STR, drying, LPG, modified blower, paddy seed.*

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1. Introduction

Rice (Oryza sativa L.) is the staple cereal crop of Bangladesh. Bangladesh has produced around 35.3 million metric ton rice from 11.8 million hectares area (USDA report, 2019). Drying of paddy is an essential post-harvest operation before storing and processing of paddy. The main objective of drying is to lower the moisture content of agricultural products to certain level in which it is suitable to long-term storage (Doymaz and Pala, 2003). Paddy is usually harvested at 20 to 25% (wet basis) moisture content and for storage purpose it is reduced to 12-14% moisture content (IRRI Rice Knowledge Bank, 2018). Sun drying is a time consuming process and it also depends on the weather conditions. Sudden change in weather such as rain and foggy weather hamper the sun-drying process. These result in delayed drying, re-wetted grains and quality deterioration which cause damage in grain and reduce the quality and market value of grain. So, alternate drying practice such as mechanical drying needs to be expanded in Bangladesh in order to improve the drying performance.

An economic hot air circulated dryer was developed in Bangladesh Agricultural University (BAU) by Post-Harvest Loss Reduction Innovation Lab-Bangladesh (PHLIL) for rapid and efficient drying (Alam et al., 2019). This dryer is called BAU-STR dryer which was adopted from STR Vietnamese low cost dryer by using locally available materials in sustainable manner for the farmers and small traders. In order to maximize the post-harvest yield, farmers need to dry the paddy as fast as possible. BAU-STR dryer can dry the paddy within a very short period of time compared to sun drying in rainy season. Performance of STR dryer on different grain bin size had been investigated (Alam et al., 2016; Alam et al., 2019). Experiment on different varieties of rice had been conducted (Alam et al., 2017). Spatial temperature distribution and neural network modeling on BAU-STR dryer were also investigated in recent years (Alam et al., 2016; Alam et al., 2018).

In primary stage, Rice husk briquette was used as heating source. But briquette has some drawbacks. Briquettes's burning capacity depends on moisture content. So, in high relative humidity condition, the briquettes' burning quality is lower than standard value. During harvesting period of *Boro* and *Aus*, the humidity of air is very high (often 80-90%) (Aktar et al., 2016). During the drying process, briquettes need to be fed frequently in the dryer. However, briquettes are not available all over the country. Liquefied Petroleum Gas (LPG) is a clean source for cooking and available all over Bangladesh.It is odorless, colorless and heavier than air, so it will not be dispersed easily without wind or ventilation (Demirbas, 2002). LPG could be a clean potential heating source for BAU-STR dryer for drying paddy. Therefore, LPG based heating system needs to be developed and tested for BAU-STR dryer for paddy drying.

2. Methodology

2.1 Design and development of LPG based heating system

In order to design a LPG based modified heating system following considerations were under taken:

- Heating unit should be capable of producing hot air of temperature 42°C at the center of the inner bin;
- The burner can be made by locally available materials; and
- Vibration of the stove needs to be stopped.

2.2 Experimental site and duration

The study was conducted at the workshop of the department of Farm Power and Machinery in Bangladesh Agricultural University. The performance study of BAU-STR dryer using LPG system as heating source was conducted during 25 November, 2019 to 11 December, 2019 (*Aman* season). The dryer was evaluated using paddy variety BRRI dhan49. The paddy samples were collected from the Agronomy field of BAU.

2.3 Treatment

The dryer's performance was evaluated by setting 2 different heating units (rice husk briquette and LPG based) and two blowers (Vietnamese and locally made modified blowers) combination. Treatment 1 (T1), treatment 2 (T2) and treatment 3 (T3) for the study were designed by combining briquette plus modified blower, LPG plus Vietnamese blower and LPG plus modified blower, respectively. Each treatment was repeated for 3 times.

2.4 Dryer installation

The installation procedure of BAU-STR dryer is quite simple and easy. BAU-STR dryer was installed on a concrete surface. At first, inner bin was placed in a plain surface and then the outer bin was placed in such a way so that the distances between the outer bin with the inner bin can remain equal in every sides. Then paddy was filled into the annular space of the grain bins uniformly. The blower was set up on the top of the inner bin of the dryer and a thick polythene sheet was used to protect hot air leaking from the top of bins. Bricks were used as additional weight on polythene sheet to restrict sheet's movement. The burner was placed in a clay based *chula* (traditional stove) for proper installation. The hot air pipe was placed between the burner and the blower. LPG (30 kg) cylinder was connected through gas pipe to the burner. Before igniting the burner, amount of oxygen supply needs to be controlled. To control the amount of oxygen entered into the burner, a circular disc attached with the burner needs to be rolled forward and backward. Forward movement of disc reduces the amount of oxygen entered inside the burner and vice versa. In rice husk briquette heating system, it was ignited and fed frequently during drying.

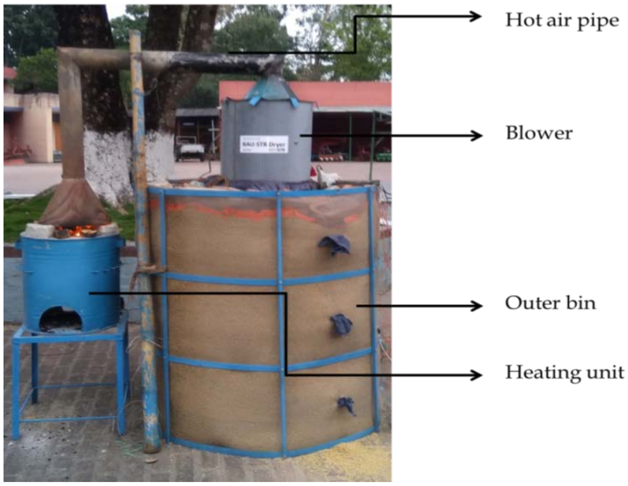


Figure 1. BAU-STR dryer

2.5 Sensor placement, measurement and analysis

The temperature sensors named Tm,29; Tm,38; Tm,47 were placed maintaining 29, 38 and 47cm distance from the center line of inner bin to record horizontal temperature distribution (Figure 2) by data-logger (CR6, Campbell scientific, USA). Top and bottom sensors were placed 28cm from top and bottom surfaces, respectively. Moisture was measured at 30 minute interval by RiceterL digital moisture meter. Ambient air temperature and relative humidity were measured continuously at same interval using ACR TRH-1000 data logger. Standard equations were used for technical and financial analyses. Milling quality of paddy was tested to judge its physical quality. Rice milling is basically the removal of husk and bran from rice kernels to obtain the edible portion for consumption.

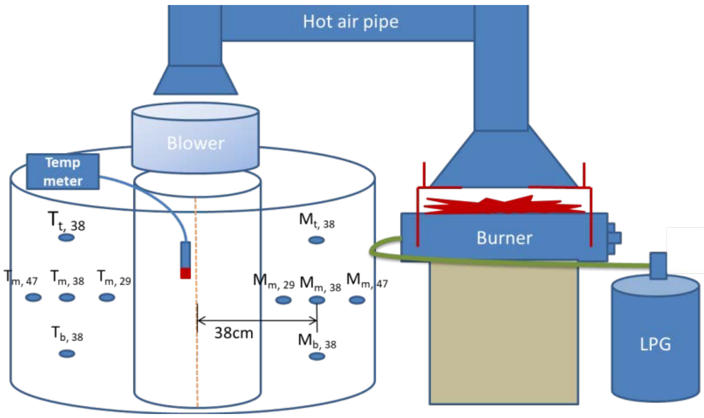
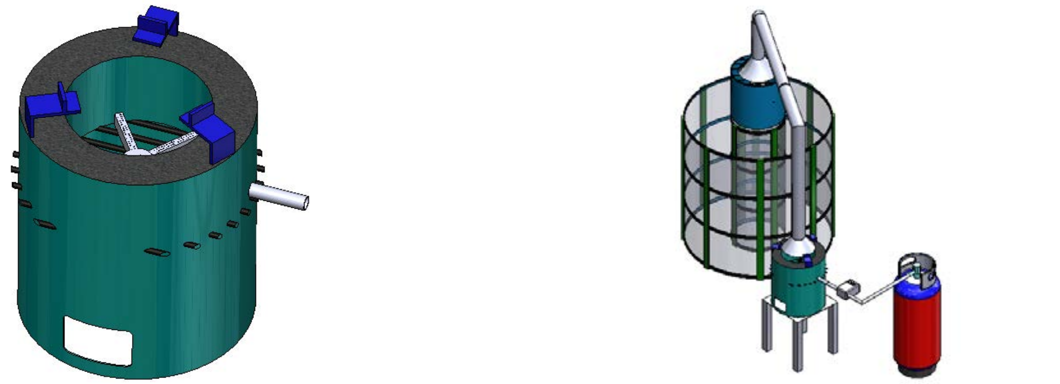


Figure 2. Experimental layout of BAU-STR dryer's temperature sensor placement and moisture measuring points (T-temperature sensors, M-moisture measuring point, t-top, m-middle, b-bottom, number in subscript indicate distance from the center line in cm).

3. Result and Discussion

3.1 Design and development of LPG based heating system

In order to develop a LPG based heating system, at first a suitable burner was selected. The selection parameter of the burner was to produce minimum temperature of 42°C at the top of inner bin after passing the heat through the blower.The previous BAU-STR dryer using rice husk briquette had some vibration issues due to the continuous running of blower at the top of the dryer. This vibration sometimes misplaced the hot air pipe from top face of the stove. So, a flat bar cover was used to restrict the movement of hot air pipe from the top face of the stove (Figure 3). The wielding of flat bars was done at the workshop of Farm Power and Machinery, BAU.



(a) Modified stove (3D)   (b) Isometric view of LPG based BAU-STR dryer

Figure 3. Development of LPG system as heating source for BAU-STR dryer

3.2 Spatial temperature distribution

Vertical temperature distribution could be understood by Tb,38, Tm,38 and Tt,38. Similarly, horizontal temperature distribution could be understood by Tm,29, Tm,38 and Tm,47. It is clear from Figure 4 that vertical temperature distribution are almost uniform but horizontal temperature distributions has difference in each location. In every treatment, temperature was varied initially among the horizontal locations because distances from the center of the inner bin were different. It was observed that during first 15 minutes of drying only the temperature of Tm,29 was increasing rapidly as it was the closest point from the inner bin. With the increases of the duration of drying, the temperature of every point tends to become almost equal which suggest the uniform distribution of temperature through the period of drying.

Heating source of treatment 1 was rice husk briquette and for treatment 2 and treatment 3, it was LPG. Treatment 1 (Figure 4) shows that temperature at Tm,29 point rises above 43˚C. It was occurred due to continuous feeding of rice husk briquette during drying. In LPG based treatments, continuous feeding during drying was not required and the gas flow was controlled by a high pressure regulator. The temperature distribution of treatment 1 and treatment 2 was almost same (Figure 4). Therefore, it is clear that LPG based treatments were more uniform and controlled in case of spatial distribution of temperature. Alam et al. (2016) stated that rice husk briquette based BAU-STR dryer were uniform in spatial distribution of temperature by controlling the rice husk briquette feeding rate but no comparison was made with rice husk briquette and LPG.

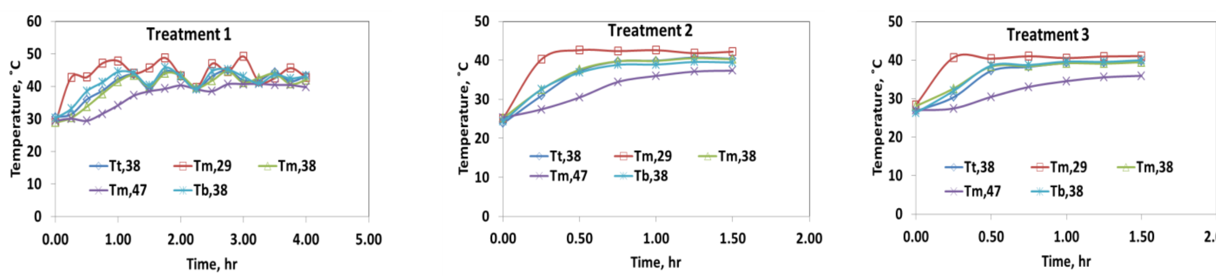


Figure 4. Drying air temperature variation of several treatments

3.3 Variation of moisture content of paddy in BAU-STR dryer

Variation of moisture content during drying in *Aman* season 2019 is presented in Figure 5. The vertical moisture distribution could be understood by Mb,38, Mm,38 and Mt,38. Similarly, horizontal moisture distribution could be understood by Mm,29, Mm,38, Mm,47. It is clear from Figure 5 that vertical moisture distribution are similar but horizontal moisture distributions has difference in each location. It is clear that the drying rate decreased with the decrease of moisture content. The gradient of moisture content between inner section (Mm,29) and outer section (Mm,47) of grain bin was very high at initial period of drying because of different horizontal distance from the center line of inner bin. The moisture gradient decreases with time and finally, reached same level in all sections of the grain bin. The required time was varied with amount of moisture removed from paddy. This pattern of drying supports the previous work on BAU-STR dryer (Alam et al., 2016; Saha et al., 2017).

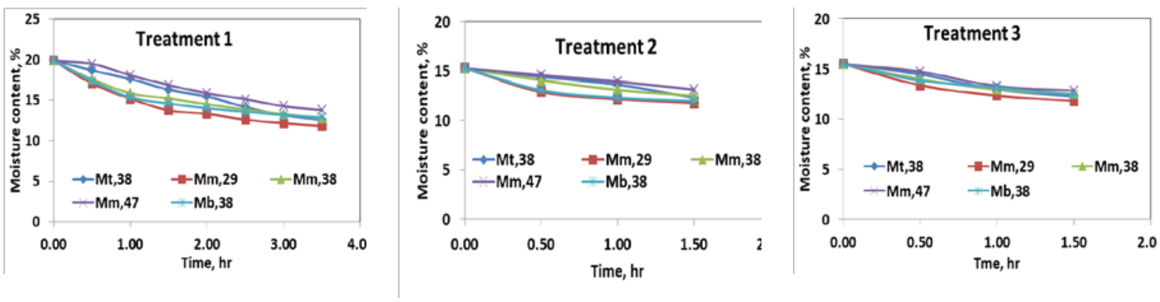


Figure 5. Variation of moisture content during at different treatments

3.4 Technical performance of BAU-STR dryer

To evaluate a machine's true quality, its technical performance needs to be evaluated. For BAU-STR dryer, its technical performance can be understood by its drying capacity, moisture removal rate, drying efficiency etc. in different treatments. The drying rate and drying capacity were varied with the variation of hot air temperature, ambient air flow and relative humidity. The drying rate was found 2%MC/hr, 2%MC/hr and 2.1%MC/hr for treatment 1, treatment 2 and treatment 3, respectively. So, it can be said that drying rate in each treatment was almost similar. The fuel consumption of rice husk briquette was found 3.36±0.11, 1.2±0.07 and 0.86±0.01 kg/hr for treatment 1, treatment 2 and treatment 3, respectively. Higher relative humidity and low ambient temperature causes more fuel consumption. Drying efficiency of treatment 1, treatment 2 and treatment 3 was found 53.9±1.6, 65.4±2 and 70.3±0.4, respectively.

Table 1. Technical performance of BAU-STR dryer

Treat ment	**Initial Moisture, %**	**Final Moisture, %**	**Relative humidity, %**	**Initial weight of Paddy, kg**	**Moisture removed, %**	**Drying time, hr**	**Drying Rate, %MC/hr**	**Efficiency, %**	**Fuel consumption , Kg/hr**
$\mathbf{T_1R_1}$	19.5	12.3	67.9±10	500	7.3	3.8	1.9	53.9	3.23
$\mathbf{T_1R_2}$	19.9	12.7	59.5±12.5	500	7.2	3.5	2.1	55.51	3.43
$\mathbf{T_1R_3}$	19.3	12.6	62.9±7.8	500	6.7	3.5	1.9	52.36	3.42
$\mathbf{T_2R_1}$	15.5	12.4	72.5±3.8	500	3.1	1.5	2.1	62.95	1.23
$\mathbf{T_2R_2}$	15.5	12.5	64.3±2.8	500	3	1.5	2	64.47	1.25
$\mathbf{T_2R_3}$	15.3	12.4	66.4±5.3	500	2.9	1.5	2	68.67	1.12
$\mathbf{T_3R_1}$	15.6	12.4	63.8±3	500	3.2	1.5	2.2	69.97	0.85
$\mathbf{T_3R_2}$	15.5	12.4	57.9±6	500	3.1	1.5	2.1	70.19	0.87
$\mathbf{T_3R_3}$	15.3	12.3	65±3.1	500	3	1.5	2	70.72	0.87

3.5 Rice quality assessment of BAU-STR dryer

Rice quality of dried paddy can be found by measuring its milling quality. Higher milling recovery means good quality of rice. Milling recovery of dried paddy sample in BAU-STR dryer is presented in Table 2. From the table it is clear that milling recovery of each treatment is almost similar. But the head rice yield (HRY) of rice husk briquette based modified is around 4.5% higher than the rest. As the optimum HRY is 50-58% (IRRI) and all the treatments have higher HRY than standard value, therefore, each treatment has ensured a significant good quality on the basis of milling.

Table 2. Milling quality of dried paddy in BAU-STR dryer

Treatment	Milling recovery, %	Head rice, %	Broken rice, %
T_1	75.6±1.9	67.4±1.2	8.2±1.4
T_2	76±1.4	63.8±4.5	12.2±3.1
T_3	75.5±1.1	62.3±1.2	13.2±0.1

3.6 Financial performance of BAU-STR dryer

Purchase price of BAU-STR dryer in treatment 1, treatment 2 and treatment 3 was 70000, 83000 and 75000, respectively with a economic life of 5 years for dryer and 10 years for blower. Total operating cost of treatment 1, treatment 2 and treatment 3 was estimated BDT 0.78/kg, BDT 1.13/kg and BDT 0.89/kg, respectively. The benefit-cost ratio was found 1.51, 0.74 and 1.18 for treatment 1, treatment 2 and treatment 3, respectively. The payback period of each treatment was found less than a year which shows that all treatments are profitable in short period of time.

4. Conclusion

LPG based heating system for BAU-STR dryer is successfully developed using locally available materials. Technical and financial performances and comparison of developed LPG based heating system with rice husk briquette based heating system for BAU-STR dryer showed that LPG based heating system does not need continuous feeding and desired temperature can be controlled easily for drying paddy. The BAU-STR dryer with LPG based heating system and locally made bower would be profitable by providing service of drying in time. The payback period of the dryer is less than one year. Further testing of BAU-STR with LPG based heating system is required for understanding field performance and farmers acceptability.

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