Use of Delta-D Technology to Prevent Paddy Straw Burning and to Produce Paddy Straw Powder in the Paddy Field which can be used as Organic Fertiliser and A Low Cost, Renewable Fuel for Thermal and Electrical Power Generation

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Abstract- *Coal is cheap compared to most other fossil fuels. However, the higher emission of CO2 has made coal, one of the major contributors to greenhouse effect, global warming and climate change on earth. Forest cover and agriculture are the main absorption systems that reduce CO2 in the atmosphere by photosynthesis. Sometimes forests are major contributors of CO2 to the atmosphere due to sporadic bushfires around the world. Agriculture, on the other hand, absorbs CO2, produces food, creates employment, and maintains a healthy, sustainable and safe eco system which never causes bush fires. Sri Lanka's major food crop is paddy, and the annual production is more than 3.5 million MT. Paddy straw (PS) is the major by-product and its annual production is more than 5 million MT. Presently, paddy is harvested by combined harvesters and after the harvest, straw stubble and cut pieces are scattered in the paddy field. Since PS is a major hindrance to field preparation for the next crop, with minimum turnaround time, most of the farmers burn PS, which causes atmospheric pollution due to emission of, heat, CO, CO2, SOx, NOx, Volatile Organic Compounds (VOC), and particulate matter. Delta-D Technology is a patented technology, invented by the author of this paper. By using Delta-D Technology all types of organic waste can be rapidly digested and converted into powder. This paper discusses research carried out by the author, to convert large quantities of PS, lying in the paddy field, into a paddy straw powder (PSP). PSP can be easily combusted in a furnace or a boiler by spraying into the combustion zone.*

Keywords: Coal alternative, paddy straw, Delta-D Technology, paddy straw powder, Solid waste

I. INTRODUCTION

Paddy is the major crop in Sri Lanka. The average paddy production is approximately 3.5 million metric tons per annum (Department of Census and Statistics, 2019). Paddy Straw (PS) is the main by-product of rice production. For every 1 MT of grain harvested, about 1.35-1.5 MT of PS remains in the paddy fields (Zhang, et al., 2013). Hence, annual production of paddy straw is around 5 million MT. This paddy straw can be used as a fuel source or as a raw material to produce organic fertilizer. PS has a very low density and has a very low commercial value because it is not used in industry or for other purposes. Hence, PS is burnt in the fields causing many environmental impacts. By using Delta-D Technology, which is described under Methodology PS can be converted into Paddy Straw Powder (PSP).

The density of PSP is 20 -25 times higher than PS (Zhang, et al., 2013). Hence, transport over long distances as well as storage and combustion of PSP becomes economically viable. It can be shown that if Delta-D Technology is used to convert 5 million MT PS into PSP and if PSP is used as a fuel to generate energy, it can produce energy equal to 3 million MT of Coal annually and also prevent emission of 8 million MT of CO_2 into the atmosphere due to PS burning in all the paddy fields in Sri Lanka.

Coal, which has a Gross calorific value (GCV) of around 6,300 kCal/kg, thermal energy of 1MT of coal is equal to around 1.6 MT of PS. Hence, 5 million MT of PSP is equivalent to around 3 million MT of Coal. However, PS has a very low density and comes out of the paddy field as large pieces. Hence, transportation, storage and combustion of PS to produce thermal and electrical energy is uneconomical. This is also another reason for burning PS in the field itself.
One of the main objectives of this research project was to ascertain whether PSP could be a substitute for coal in a coal power plant. The only coal power plant in Sri Lanka is the Lakvijaya Power Plant in Puttalam, which has a capacity of 900 MW and burns around 3 million MT of coal per annum emitting around 8 million MT of CO_2 in Sri Lanka.

At present, a significant amount of foreign exchange is spent on importing coal. In this study, PSP is introduced as an alternative source of fuel, because it has a high GCV. However, the convenience of logistics to use paddy straw as fuel can introduce many challenges. The study focuses on a method of converting the PS into a powder form that has higher density and can be stored and transported more conveniently.

Transport over long distances as well as storage and combustion of PSP becomes economically viable due to the higher density of PSP as opposed to PS. It can be shown that if Delta-D Technology is used to convert 5 million MT PS into PSP and if PSP is used as a fuel to generate energy, it can produce energy equal to 3 million MT of Coal annually and also prevent emission of 8 million MT of CO_2 into the atmosphere due to PS burning in all the paddy fields in Sri Lanka (Muhammad, et al., 2020).

II. RESEARCH PROBLEM

A. Paddy Straw Burning

PS is made up of 70% combustible organic matter, such as Cellulose ($C_6H_{10}O_5$) and others (Perera, 2008).

$$(C_6H_{10}O_5)_n + 6nO_2 \longrightarrow 6nCO_2 + 5nH_2O$$

According to the above equation, by burning 1MT of cellulose 1.63MT of CO_2 is produced. Therefore by burning about 6 million MT of paddy straw, about 8 million MT of CO_2 is emitted to the atmosphere annually. This significantly leads to global warming and climate change. If carbon trading is reintroduced, Sri Lanka can earn around USD 96 million per annum (at the past rate of USD 12 per ton of CO_2, due to the said reduction in the emission, saving, of CO_2 into the atmosphere.

B. Comparison of PS Burning and Coal Burning

$$C_{(s)} + O_{2\,(g)} \longrightarrow CO_{2\,(g)}$$

Sri Lanka imports about 3 million MT of coal per year for power generation. This amount is poised to increase with new expansion projects to increase coal-based power generation in Sri Lanka. Approximately 3.66 MT of CO_2 is produced by burning 1 MT of coal.
Hence, if we could replace coal by PS which is burnt in fields,

GCV of Coal = 6225 kcal/kg
GCV of Cellulose = 5746 kcal/kg

PS consists of 70% Cellulose;

GCV of Paddy Straw = 5746 kcal/kg × 70% = 4022 kcal/kg

Theoretical paddy straw requirement per kg of Coal = (6225 kcal/kg)/(4022 kcal/kg) = 1.54

C. Consequences of PS burning

Every year, farm fires including PS burning in the surrounding states in India, have continued to cause many problems for people, fauna and flora of India. Farmers often opt to burn paddy despite government recommendations to compost the waste due to practical reasons. Due to the low moisture content in the paddy and direct exposure to the sun, the retained moisture in dry straw is very limited. Due to this reason, naturally occurring microbial activity is highly restricted. Therefore, many farmers resort to burn the paddy straw to reduce the turnaround time in utilizing the land to cultivate more crops. Despite having in place regulations against stubble burning and paddy straw burning, it was reported that there were many incidents of farm fires in Haryana and Punjab contributing to the poor quality of air due to carbon particles, volatile organic particles and combustion gases (Ren, et al., 2019). The situation is similar though better in China, Stubble burning is still practiced.

Pollution from PS burning added to emissions from millions of vehicles, construction and road dust raise pollutants in Delhi's air by over six times the permissible limit. The smoke often rises and swarms over Delhi, especially during winters, when the city is most vulnerable to toxic smog. The smoke contains toxic substances, including particles that have diameter of less than 2.5 micrometres ($PM_{2.5}$), carbon monoxide (CO), methane (CH_4), carbon dioxide (CO_2) and oxides of nitrogen and sulpher (NO_x and SO_x) (Perera, 2001). The situation is similar in other mega cities, such as Mumbai and Calcutta.

It is estimated that approximately 200 million MT of PS is produced in India alone annually. Burning PS causes health problems such as breathlessness, asthma, chronic bronchitis and other respiratory disorders, besides eye irritation and reduced resistance to cold and lung infections. While inhaling, fog, smog or smoke components enter our lungs. It creates hypersensitivity in those already suffering from asthma bronchospasm, making it even more difficult for them to breathe

(Chawala & Sandhu, 2020) (Krutika & Arvind, 2020).

Figure 01: Paddy Straw and Stubble Burning causing the great Delhi Smog - Source: www.scroll.in

In 2017, Sri Lanka experienced an energy crisis due to the breakdown of 2 out of 3 generators in the Lakvijaya coal power plant in Sri Lanka. A root cause analysis carried out by the team of engineers attached to the CEB found out the particulate matter emitted during burning of paddy straw in a vast area may have contributed to damages causing the breakdown of a distribution station in the Ampara district which resulted in the island-wide power outage.

III. METHODOLOGY

A. Introduction to converting PS into PSP using delta d technology

In this research project, paddy straw power is used as the fuel source. After the converting process of paddy straw into their powder form density value is increased. Therefore, the transportation cost is reduced and the generating cost can be reduced. Also, straws are fluffy, flexible, bad floating; paddy straw could be twisted and jammed in feeding and conveying. But by using paddy straw powder above problem couldn't be occurred. Paddy straw powder can be fed into the boiler using high-pressure airflow rate as same the coal powder feeding.

B. Introduction to Delta- D Technology

Delta D technology is a patented technology developed by Perera, Author 1 of this paper. With the combination of Delta-D technology and solar energy, sunlight rapidly digests biomass. Delta-D has a chemical combination that can digest all types of natural organic matter by catalyzing it. So, when it is digested it becomes a powder without affecting the chemical composition. Leachate or an unpleasant odor is not created from it (Perera, 2012).

C. Types of Delta-D

Different types of Delta-D are available to choose based on the type of waste that has to be digested (Perera, 2007).

- Delta-D^C: This is specifically used for high cellulose materials such as straw, sawdust, grass, leaves of plants, waste paper, etc.
- Delta-D^P : This type is specifically used for high protein material, such as, excreta of animals, poultry farm waste, fish waste, slaughterhouse waste, etc.
- Delta-D^V :This type is used specifically for low cellulose high moisture material, such as fruit and vegetable waste, cooked food waste, etc.
- Delta-D^{USW} :This is used for urban solid waste, which is a mixture of, fruit and vegetable waste, cooked food waste, waste paper, etc.

In this research project, Delta-D^C will be used hereinafter termed as Delta –D.

D. Process of converting PS into PSP using Delta D technology

Recommended Method for Rapid Digestion of Rice Straw in Dry Zones
35 kg of dry rice straw is wetted with a solution of 1litre of Delta-D^C and mixed with 50 liters of water. The wetted straw is laid on plastic sheets and exposed to the sun for 3 days. After 3 days the straw crumbles into powder.

E. Recommended Method for Rapid Digestion of Rice Straw in Wet Zones

Even in the wet zones of Sri Lanka there is ample sun shine right through the year. Hence, above method can be practiced most of the time. However, if there are rains and it is not possible to expose the straw to sunshine, the following method should be followed

F. PSP production

Conversion of paddy straw into paddy straw powder could be done by mechanical grinding. However, it is challenging to grind paddy straw due to its elastic fibrous nature and inability to carry out grinding in-situ. Powder produced using the Delta-D technology can be used to produce fuel briquettes or high value-added products such as MDF (Medium Density Fibre) Boards, etc. Paddy straw can be converted into paddy straw powder within 2-4 days using a combination of

Delta-D Technology and solar energy (sunlight). (Perera, 2007a) (Perera, 2007b) (Perera, et. al.,2017).

Paddy straw is not used as a source of fuel due to its very low density. Therefore, transportation of paddy straw over long distances is not economically feasible. Converting PS to PSP using the Delta-D Technology at the Roof Top of Department of Chemical and Process Engineering of University of Moratuwa.

35 kg of dry paddy straw was wetted with a solution of 1litre of Delta-D[c] and mixed with 50 litres of water. The wetted straw is laid on plastic sheets and exposed to the sun for 3 days. After 3 days the straw crumbles into powder.

G. Determination of the Calorific Value of PSP

The produced paddy straw powder was compressed and pelletized. The gross calorific value of the paddy straw powder was obtained using ASTM D 5865 test method. The heat capacity of the calorimeter was determined by burning a specified mass of benzoic acid in oxygen. A comparable amount of the analysis sample was burned under the same conditions in the calorimeter. The calorific value of the analysis sample was computed by multiplying the corrected temperature rise, adjusting for extraneous heat effects, by the heat capacity and dividing by the mass of the sample.

H. Density of Paddy straw powder

The bulk density is determined by ASTM E873 method. This test method covers the procedure for the determination of bulk density of densified particulate biomass fuels with a maximum particle volume of 16.39 cm^3. An empty box with a known volume is taken and weighed and recorded its weight. Then the box is filled by pouring from a height of 610 mm above the top edge of the container. The box is dropped five times from a height of 150 mm on to a no resilient surface to allow settling. Then additional sample is added and stroke off the excess sample level with the top edge. Then the box and sample is weighted to and recorded the total weight. Finally dividing the biomass weight by volume of box, the bulk density of the biomass can be calculated.

I. Moisture Content of PSP

Moisture content is determined using the method of ASTM E790. An original sample was obtained and placed in an airtight container immediately after collection. Then an empty container with its cover was dried at 107±3 °C in the oven and then cooled in desiccator to room temperature for 15-20min. The covered container was weighed and recorded (W_c) to the nearest 0.01 g. Then approximately 1 g of sample is placed in the covered container and recorded the initial weight (W_i). The sample and uncovered container is placed in the preheated oven to 107±3 °C for 1h and final weight of sample, cover and container (W_f) is recorded after cooled in a desiccator. The moisture content can be calculated by following equation.

Moisture content

$$Moisture\ content\ of\ the\ smple = \left[\frac{(W_i - W_f)}{(W_i - W_c)}\right] \times 100\%$$

J. Volatile matter of PSP

The volatile matter is determined by ASTM E872 method. The crucible and cover is weighed to the nearest 0.01 g and recorded as crucible weight, W_c. Then approximately 1 g of sample is placed in the crucible, covered, and weighed the crucible, cover and sample to the nearest 0.01 g, and recorded as initial weight, (W_i). The covered crucible with the sample is placed at 950 ± 20 °C for 7 minutes then cooled in desiccator to room temperature. Then the final weight of crucible, cover and sample (W_f) is recorded. The volatile matter content is calculated by using below equations.

$$Weight\ loss = \left[\frac{(W_i - W_f)}{(W_i - W_c)}\right] \times 100\% = A$$

$$Volatile\ matter\ in\ the\ sample, \% = A - B$$

A= weight loss, %

B= moisture content, %

K. Ash content of PSP

The ash content is determined by using ASTM E830 method. The empty container and cover are dried at 107±3 ˚C in the oven and then cooled in desiccator to room temperature for 15-20 min. The covered container weight (W_c) is recorded to the nearest 0.01 g. Then a minimum of 1 g of sample is placed in the previously fired container and recorded the initial weight (W_i). After, the uncovered container containing the sample is placed in the furnace at low temperature and gradually heat to 575±25 ˚C for 1 hour.After Cooled in a desiccator to room temperature the final weight of sample, cover and container (W_f) is recorded.

The ash content in the sample can be calculated by following equation.

$$A = \left[\frac{(A-B)}{C}\right] \times 100\%$$

A = weight of container and ash residue
B = weight of empty container
C = weight of ash analysis sample

IV. RESULTS AND DISCUSSION

A. PSP production

Produced PSP was pelletized and PSP pellets were produced.

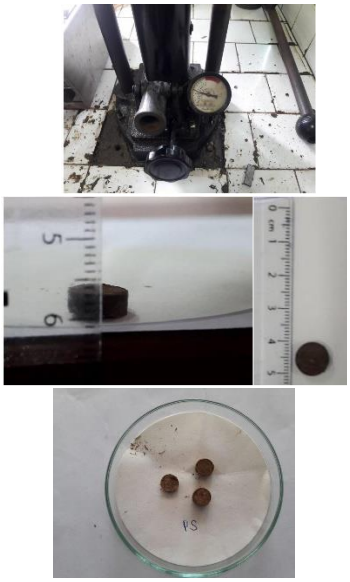

Figure 02: Produced PSP pellets

B. Calorific Value of PSP

The gross calorific value of the paddy straw powder was tested at ITI – Industrial Technology Institute and was found to be 3124 kcal/kg.

C. Density of PSP

The obtained values for the density values of PS and PSP are as follows:

Density of paddy straw = 20.4 kg/m^3
Density of paddy straw powder = 490 kg/m^3

After the converting process of paddy straw into its powder form, density value increases. Therefore the transportation cost can be reduced as the limiting factor is the transportable volume instead of transportable mass in this case. Paddy straw powder can be fed into boilers using high pressure air flow rates similar to coal powder feeding.

D. Moisture content, volatile matter and ash content of PSP

The moisture content values for PS and PSP were obtained as

Moisture content of paddy straw = 15.6 w/w

Moisture content of paddy straw powder = 23.85 w/w

Volatile matter = 43.20%

Ash content of paddy straw powder = 30.32%

Table 01: Summary of physical characteristics of paddy straw powder

Property	**Quantity**
Density	490 kg/m^3
GCV	3124 kcal/kg
Ash Content	30.32%
Moisture content	23.85%

E. Results of Field Trials Carried out to Determine Practical Use of Paddy Straw Powder in Boilers

i. Research Project at Sena Pura Rehabilitation Camp (SPRC) For Disabled Soldiers:

At the request of Major Piyumal Piyatissa, Acting CO of the SPRC, a project was carried out to convert PS into PSP. 1 acre of paddy was harvested manually and brought to land and was threshed with a machine to separate seeds from straw. PS was spread on land at a thickness of 1 inch. Delta-D was diluted with water at the ratio 1:50 and was sprayed on to PS and was subjected to direct sunshine for 2 days. After 2 days PS crumbled into a powder (PSP) and was sifted through a mesh of size 40 and the powder was packed into bags and weighed. The weight was 900 kg. This PSP was transported to a nearby Paddy Par Boiling Mill which a paddy husk had fired Cochran Boiler, which was operating at a pressure of 100 psig and was producing steam at a temperature on 140 ºC. With the consent of the owner of the mill and with the assistance of the boiler, PSP was fired in the boiler. It was found that PSP burnt better than Paddy Husk, since unburnt PSP was very low compared to burning of Paddy Husk, which had unburnt material, as much as 30% of the original weight. Steam production from 900 kg of PSP was around 3000 kg.

ii. Research Project at Embilipitiya:

A project was carried out to in a paddy field owned by Mr. Leonard, where PS from a 2 acre paddy field was converted into PSP using Delta-D^c. The 2 acre paddy field was harvested using a combined harvester. PS pieces were scattered in the paddy field and could not be collected into bags. Hence, using rakes PS was evenly spread in the paddy field to a thickness of 0.5 inches. Delta-D was diluted with water in the ratio 1:50 and was sprayed on to PS and was subjected to direct sunshine for 2 days. After 2 days PS crumbled into a powder (PSP) and was collected into bags using industrial vacuum cleaners and later was sifted through a mesh of size 40 and the powder was packed into bags and weighed. The weight was 1600 kg. This PSP was transported to a nearby Paddy Par Boiling Mill which had a paddy fired Boiler, which was operating at a pressure of 80 psig and was producing steam at a temperature on 110 ºC. With the consent of the owner of the mill and with the assistance of the boiler operator, PSP was fired in the boiler. Here again it was found that PSP burnt better than Paddy Husk, since unburnt PSP was very low compared to burning of Paddy Husk, which had unburnt material. Steam production from 1600 kg of PSP was around 4500 kg.

V. CONCLUSION

Since total paddy production in Sri Lanka is 5 million MT, approximately 2.5 million MT of imported Coal can be replaced from paddy straw, since, PSP has a gross calorific as 3124 kcal/kg, whereas, coal has a gross calorific value of around 6,200. Farmers burn PS in the paddy field itself, since. PS has a very low density and PS transport to a Paddy Parboiling mill or a furnace is uneconomical. PS burns very fast and temperature control is impossible. Delta-D technology can transform low density PS into a high density powder that can be economically transported to a boiler or cement kiln Compared to fossil fuel, such as, furnace oil or coal PSP is carbon neutral and is a good fuel to produce thermal or electric power generation. Preparation of PSP is cheap and no foreign exchange is involved. Converting PS to PSP is easy and handling, storage and transport is easy, since, no storage tanks, conveying systems are required. Since Paddy is a seasonal crop PS is also seasonal and PSP production is also seasonal. Hence, an efficient and low cost storage method should be developed, such as silo systems with safety aspects, preventing dispersion of powders in air and dust explosions. Pelletizing PSP is an attractive but expensive proposition. If PSP is to be used as a fuel, Biomass Boilers have to be modified to fire PSP efficiently, since, it is a fine powder compared to wood chips, paddy husk, etc., which are large particles. If PSP is used as a fuel, it can replace half its quantity of coal, thereby saving valuable foreign exchange and also preventing air pollution, due to haphazard burning of PS all over the country

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