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Dry fermentation technology for utilization of Bio-energy crops/crop residues for biogas production

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Abstract: Indian state Punjab produces 160 lakh tones of paddy every year. More than this quantity of paddy, straw is also produced which is not properly utilized. Paddy is burnt in the farmer's fields itself, which produces lot of smoke and atmospheric pollution. Farmers have their own difficulty for burning this valuable straw as they have to vacate the fields for the next crop. Biogas production is one alternative for the individual farmer, for individual village or on the regional basis. In our opinion, it is possible to digest paddy straw anaerobically for biogas production and the digested humus would be utilized as crop manure. Anaerobic digestion of crop waste cannot be done by conventional anaerobic process for biogas production because of the floating characteristics of paddy straw in water. New process of anaerobic digestion has to be followed with small quantity of water to avoid floating of paddy straw. This process is commonly known as dry fermentation. This technique is well known in United States, Taiwan, German and Sri Lanka. In these countries, steel containers are being used as digester for anaerobic digestion. Digester of steel is ideal but the cost involved is very huge. Attempts have been made at PAU to construct masonry structure as digester but lot of difficulties were being faced to make it gas tight. The PAU has found suitable method to make the digester strong and gas tight. The life of structure will be more than 15 years. The advantage of the masonry structure is that the whole structure will be underground on which cold would have little effect in winter. This process of Dry Fermentation is a batch process, once the digester is loaded and activated, would produce sufficient gas for a period of 3 - 4 months. Therefore, 2 sets of digester are required to meet the whole year demand.

Key words: Dry Fermentation, Paddy Straw, Biogas, Batch Process, Anaerobic process

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Introduction: The role of new and renewable energy has been assuming increasing significance in recent times with the growing concern for the country's energy security. Due to escalating cost of petrol and diesel, Bio-energy is gaining importance.

There is excessive shortage of conventional type of fuel in the country and there is heavy demand of alternate non-conventional fuel. One such fuel is biogas produced by anaerobic digestion of organic wastes. Biogas, a clean and renewable form of energy could be a very well substitute (especially in the rural sector) for conventional sources of energy (fossil fuels, oil, etc.) which are causing ecological–environmental problems and at the same time depleting at a faster rate. Despite its numerous advantages, the potential of biogas technology could not be fully harnessed or tapped as certain constraints are also associated with it. Most common among these are: the large hydraulic retention time of 30–50 days, low gas production in winter, etc. Therefore, efforts are needed to remove its various limitations so as to popularize this technology in the rural areas. Researchers have tried different techniques to enhance gas production.

Paddy straw is available in our country in plenty and is being used as an inferior cattle feed or is being burnt in the fields to vacate the fields for the next crop which cause atmospheric pollution. It is not being used properly, one of this method of useful disposal of paddy crop is anaerobic digestion by dry fermentation technique for the production of biogas. This method is most recent and is being tried in USA. The method of "dry fermentation" refers to anaerobic methane fermentation where there is no free or drainable water in the crop residues.

The dry fermentation of crop residue appeared to simplify and enhance the possibilities of using crop residues as an energy source. In frequent loading of the system and relatively dry effluent residues showed that small units for residential use, farm scale community size systems were potentially feasible. Further, on-farm use of the system would provide a four- to ten-fold increase in energy production potential over that available "in animal manures, while the plant nutrients" would be efficiently immobilized for further fertilizer use.

Batch reactors are required for a dry system, as compared to continuous feed methods. This is primarily related to field collection, transport and storage methods for crops and crop residues. Loading of batch reactor will be assumed to minimize labour requirements and residue handling and pretreatments needs.

Indian state Punjab produces 140 lakh tones of paddy every year. More than this quantity of paddy, straw is also produced which is not properly utilized. Paddy is burnt in the farmer's fields itself, which produces lot of smoke and atmospheric pollution, which causes health problems to the human beings. Farmers have their own difficulty for burning this valuable straw as they have to vacate the fields for the next crop and the duration for this is only 2-3 weeks. We are of the opinion that this straw is to be used for useful purpose. Biogas production is one alternative for the individual farmer, for individual village or on the regional basis. This would have own difficulties. The carriage of paddy straw to far off places would be very difficult and at the same time its storage at one place requires lot of space, time and funds. Due to this difficulty biomass thermal plants working on crop wastes including paddy straw are not functioning to their capacities. In my opinion, it is possible to digest paddy straw anaerobically for biogas production and the digested humus would be utilized as crop manure. This would not only enhance the health of the field, but also freedom from atmospheric pollution and biogas would be a good source of energy.

Anaerobic digestion of crop waste cannot be done by conventional anaerobic process for biogas production because of the floating characteristics of paddy straw in water. New process of anaerobic digestion has to be followed with small quantity of water to avoid floating of paddy straw. This process is commonly known as dry fermentation. This technique is well known in United States, Taiwan, German and Sri Lanka and is used for biogas production. In these countries either steel containers or red mud plastic sheet are being used as digester for anaerobic digestion. Digester of steel is ideal but the cost involved is very huge. Red mud plastic is a new flexible plastic material which can be stretched to a length of 2.5 times the length of unexpanded plastic. The life of this plastic is more than 7-8 years.

Attempts have been made at School of Energy Studies for Agriculture, PAU to construct masonry structure as digester instead of above materials but lot of difficulties are being faced to make it gas tight. The School is endeavoring to find suitable method to make the digester strong and gas tight. It is hoped it will be achieved in due course of time. Once the digester is air tight, there will be no problem for generating biogas from paddy straw and the life of structure will be more than 15 years. The advantage of the masonry structure is that the whole structure will be underground on which cold would have little effect in winter. This process of Dry Fermentation is a batch process, once the digester is loaded and activated, would produce sufficient gas for a period of 3-4 months. Therefore, 4 sets of digester are required to meet the whole year demand. All such 4 digesters are to be loaded during this paddy straw harvesting and consequently will be activated depending upon the quantity of biogas required. If biogas required is for the short duration, all the 4 units can be activated simultaneously.

REVIEW OF LITERATURE:

Paddy straw and husk are the waste products of the rice crop and are seen with hatred. The depletion of fossil fuels and the almost steep rise in oil price have contributed their share in the present energy crisis. These days the problem of energy shortage is experienced every sphere of life. Paddy waste has high heat potential and thus has attracted the attention of scientists and technologists. Rice straw is the least used paddy waste in Punjab. Less than 20 % of rice straw is used as cattle feed, bedding and for paper and cardboard production. A major portion of it is burnt in the fields to make room for the next crop. The husk used to pose a problem for disposal till late 70's. However the shortage of coal has induced the potential users to use husk in furnaces and brick kilns. It is also used as a packing material to protect eggs, porcelain wares and other fragile structures from damage. It is also used for making insulation boards. Considering its utility, a study is conducted to explain the usefulness of this practically no cost fuel for generation of power. **[1]**.

The feasibility of utilising energy crops and crop residues in methane production through anaerobic digestion in boreal conditions was evaluated. Potential boreal energy crops and crop residues were screened for their suitability for methane production, and the effects of harvest time and storage on the methane potential of crops was evaluated. Co-digestion of energy crops and crop residues with cow manure, as well as digestion of energy crops alone in batch leach bed reactors with and without a second stage upflow anaerobic sludge blanket reactor (UASB) or methanogenic filter (MF) were evaluated. The methane potentials of crops, as determined in laboratory methane potential assays, varied from 0.17 to 0.49 m^3 CH_4 kg^{-1} VS added (volatile solids added) and from 25 to 260 m^3 CH_4 t^{-1} ww (tons of wet weight). Jerusalem artichoke, timothy-clover and reed canary grass gave the highest methane potentials of 2900–5400 m^3 CH_4 ha^{-1}, corresponding to a gross energy potential of 28–53 MWh ha^{-1} and 40,000–60,000 km ha^{-1} in passenger car transport. The methane potentials per ww increased with most crops as the crops matured. Ensiling without additives resulted in minor losses (0–13 %) in the methane potential of sugar beet tops but more substantial losses (17–39 %) in the methane potential of grass, while ensiling with additives was shown to have potential in improving the methane potentials of these substrates by up to 19–22 %. In semi-continuously fed laboratory continuously stirred tank reactors (CSTRs) co-digestion of manure and crops was shown feasible with feedstock VS containing up to 40 % of crops. The highest specific methane yields of 0.268, 0.229 and 0.213 m^3 CH_4 kg^{-1} VS added in co-digestion of cow manure with grass, sugar beet tops and straw, respectively, were obtained with 30 % of crop in the feedstock, corresponding to 85 – 105 % of the methane potential in the substrates as determined by batch assays. Including 30 % of crop in the feedstock increased methane production per digester volume by 16 – 65 % above that obtained from digestion of manure alone. In anaerobic digestion of energy crops in batch leach bed reactors, with and without a second stage methanogenic reactor, the highest methane yields were obtained in the two-stage process without pH adjustment. This process was well suited for anaerobic digestion of the highly degradable sugar beet and grass-clover silage, yielding 0.382 – 0.390 m^3 CH_4 kg^{-1} VS added within the 50 – 55 day solids retention time, corresponding to 85 – 105 % of the methane potential in the substrates. With the more recalcitrant substrates, first year shoots of willow and clover-free grass silage, the methane yields in this process remained at 59 – 66 % of the methane potential in substrates. Only 20 % of the methane potential in grass silage was extracted in the one-stage leach bed process, while up to 98 % of the total methane yield in the two-stage process originated from the second stage methanogenic reactor. Liquid and solid residues from digestion of grass-clover silage and sugar beet in two-stage leach bed – MF processes were suitable for incorporation to soil as fertiliser and soil-improvement media, whereas in the solid residue from digestion of willow, cadmium concentration exceeded the limit value for use of digestives as fertiliser in arable land **[2]**.

Agricultural products are a source of readily-collectable biomass that could be converted to a clean, useable fuel (methane) using anaerobic fermentation (Carter 1978; Office of Technology Assessment, 1978). Non-food organic residues contributed from all farmland in the U.S. could be used to produce, annually, more than US $ 30 billion worth of energy. Increased plant production and utilization of presently idle land could increase this amount to as much as one-third of the total U.S. energy demand, thus potentially exceeding the present amount of all imported fuels. As will be seen, it appears that methane generation from organic residues can be implemented in many agricultural operations, and can result in the production of a significant amount of substitute natural gas (biogas) at costs that are competitive with existing fuel sources. This can be accomplished using a technology that conserves valuable plant nutrients and soil humus and thus encourages improvement of crop production capability **[3]**.

The application of anaerobic fermentation on individual farms has been difficult to justify because of the small size and limited capital and operational skills on these farms. However, it may be the area where this method of clean and renewable fuel generation holds greatest potential for contributing to the energy problem. This paper (Jewell, *et al*, 1976; Jewell *et al*, 1978; Jewell *et al* 1980) summarizes the ongoing work on anaerobic fermentation by a multi-disciplinary team of researchers at Cornell University since 1973. The main emphasis has been to develop a practical and economically feasible farm-scale methane generation system **[4]**.

The decomposition and gas production pattern of unprocessed biomass feed stocks representing annual weeds, leaf litter, agro-residues and market wastes were monitored in this laboratory study. Solid phase fermentation was effected with a weekly fed biomass bed sprinkled twice daily with recycled fermented liquid to initiate and sustain biogas production from the decomposing biomass bed. Fomenters were fed from the top with gradually increasing feed rates to determine maximum feed rates sustainable. Feed rates of 1 g total solids (TS) $l^{-1}d^{-1}$ was possible which lead to pseudo steady state gas production rates between 0.26±0.98 l l^{-1} dÿ1 at speci®c gas yields of 0.18±0.44 l g^{-1} TS at 35±75% volatile solids (VS) destruction. Feed stocks such as paper mulberry (Broussenetia), Parthenium, Synedrella and urban garbage lost > 50% VS in 30 d while paddy straw, bagasse and sugarcane trash exhibited lower VS loss (r35%) in this period. During decomposition, bulky biomass feed stocks underwent compaction and obviated the need for a pretreatment step. Bulk densities rose manifold to reach between 150±350 g l^{-1} within 20 d. A higher decomposition rate, process optimization and use of pre-compacted feed stocks have the potential to increase the feed rates (0.96±1.93 g TS $^{-1}$1d^{-1}), quantity of feedstock held in the reactor as well as gas production rates. The current gas production rates and space economy in these fomenters compare well with Indian cattle dung fomenters (0.3±0.5 l l^{-1} d^{-1}) **[5]**.

Proponents of agricultural residue use for energy production need to show that this is a rational choice in terms of economics, energetics and environmental impact. Towards this goal, a complete (life cycle) cost, energy and atmospheric emissions accounting for rice straw utilization in energy production is compared with other rice straw management practices. Two energy production systems are examined, direct combustion in a biomass facility to produce electrical energy and anaerobic phased-solids (APS) digestion to produce biogas for energy use. The rice straw harvesting/utilization system has a cost and energy use of US $ 38.33/Mg of dry straw and 1271 MJ/Mg of dry straw respectively compared with in-field alternatives of open-field burning (US $1.25/Mg, 71 MJ/Mg) and incorporation/flooding (US $13.51/Mg, 469 MJ/Mg). Cost reductions or incentives of at least US $12/Mg are still needed to meet revenue requirements for rice straw combustion in biomass power plants. The APS digester system can be cost competitive if natural gas prices remain high and if capital costs are in the US $1000/kW range.

Both systems show a positive energy balance to cover the 3820 MJ/Mg of primary energy required for the production system, given a rice straw higher heating value of 16000 MJ/Mg and a biogas production rate of 6813 MJ/Mg. The emissions balance shows that straw utilization for power production is a “cleaner” solution than open-field burning for all pollutants tracked and for methane and ammonia relative to incorporation/flooding. Municipal Solid Wastes (MSW) are being generated in increasing quantities and is a major source of organic waste, that emits biogas or greenhouse gases that contribute to the global warming effect. If the biogas can be harvested and used for generating electricity, it would be a valuable source of renewable energy. It would not only help reduce greenhouse gas emission but also help reduce the use of fossil fuels for electricity generation. Our dry fermentation anaerobic digestion plants are particularly suitable and efficient for converting the organic fraction of MSW to biogas, and thence for electricity generation. In the process, the residual digestate can be processed into valuable fertilizer or soil conditioner. Furthermore, by utilizing the organic fraction of MSW in this way, this fraction need not go to the landfill, thus enabling the lifespan of the landfill to be extended **[6]**.

There are the methods available to enhance biogas production from manure and straw. Information is given on the effects of retention time, temperature, high temperature pre-treatment, addition of trace elements, addition of surface active elements, addition of enzymes, addition of bacteria, co-digestion of manure with straw and co-digestion of manure with straw pre-treated with fungi. Methane yields of 380 l/kg volatile solids (75 % energy recovery) can be obtained with mixtures of manure and straw and long retention times (120 days). High solids digestion of cattle manure with long retention times in family-size digesters gave methane yields of 230 l/kg volatile solids (45 % energy recovery) **[7]**.

The biogas yield of rice straw during anaerobic digestion can be substantially increased through solid-state sodium hydroxide (NaOH) pretreatment. This study was conducted to explore the mechanisms of biogas yield enhancement. The chemical compositions of the pretreated rice straw were first analyzed. Fourier transform infrared (FTIR), hydrogen-1 nuclear magnetic resonance spectroscopy (1H NMR), X-ray diffraction (XRD), and gas permeation chromatography (GPC) were then used to investigate the changes of chemical structures and physical characteristics of lignin, hemicellulose, and cellulose. The results showed that the biogas yield of 6 % NaOH-treated rice straw was increased by 27.3 - 64.5 %. The enhancement of the biogas yield was attributed to the improvement of biodegradability of the rice straw through NaOH pretreatment. Degradation of 16.4 % cellulose, 36.8 % hemicellulose, and 28.4 % lignin was observed, while water-soluble substances were increased by 122.5 %. The ester bond of lignin-carbohydrate complexes (LCCs) was destroyed through the hydrolysis reaction, releasing more cellulose for biogas production. The linkages of inter-units and the functional groups of lignin, cellulose, and hemicellulose were either broken down or destroyed, leading to significant changes of chemical structures. The original lignin with a large molecular weight and three-dimensional network structure became one with a small molecular weight and linear structure after NaOH pretreatment. The cellulosic crystal style was not obviously changed, but the crystallinity of cellulose increased. The changes of chemical compositions, chemical structures, and physical characteristics made rice straw become more available and biodegradable and thus were responsible for the enhancement of the biogas yield **[8]**.

Rice straw was fermented with *Cellulomonas sp.* and *Alcaligenesfaecalis.* Microbial cells and undigested residue, as well as chemically treated (NaOH or NH_4OH) and untreated straws, were analyzed for nutrient composition and in-vitro digestibility. In a typical fermentation, 75 % of the rice straw substrate was digested, and 18.6 % of the total substrate weight that disappeared was recovered as microbial protein. The microbial cell fraction was 37 % protein and 5 % crude fiber; the residue was 12 % protein and 45 % crude fiber. The microbial protein amino acid profile was similar to alfalfa, except for less cysteine. The microbial cells had more thiamine and less niacin than Torula yeast. In-vitro digestibility of the microbial protein was 41.2 to 55 %; that of cellulose was 52 % **[9]**.

Little information exists to define the requirement of dry anaerobic fermentation although it has been used on practical scale by the farmers in Europe and other areas. Buswell (1936) developed a reactor especially designed for fibrous material and Ducellier and Isman (1952) used sites filled with manure and bedding as methane generators. No information on the kinetics or the economics of these systems exists. Two early studies reported by Schulze (1958) and Keefer (1947) achieved successful digester of sewage solids at 20 % solids and greater. Recently, the feasibility of achieving efficient methane production from high solids organics has been under review by Cornell project and others. On a laboratory scale study in 1976, it was shown that the rate-of and efficiency-of conversion of a mixture of straw and dairy cow manure with initial solids at 25 % dry matter were close to control decay rates in a 10 % solid mixture (Jewell et al, 1978). Subsequently, Wujcik and Jewell (1979) conducted detailed studies of the effects of water content on the role of methane production on via mesophilic anaerobic fermentation. This study attempted to define the limits of moisture and chemicals had on hydrolysis reactions, the acid forming mechanisms and finally methane production. This study confirmed the potential of starting and controlling the dry anaerobic fermentation reaction **[10]**.

The dry anaerobic digestion process is an innovative waste-recycling method to treat high-solid content bio-wastes. This can be done without dilution with water by microbial consortia in an oxygen free environment to recover potential renewable energy and nutrient-rich fertilizer for sustainable solid waste management. It generally takes place at solid concentrations higher than 10 % and enables a higher volumetric organic loading rate, minimal material handling, lower energy requirements for heating, limited environmental consequences and energetically effective performance. The long retention time, poor startup performance, incomplete mixing and the accumulation of volatile fatty acids (VFAs) are considered as the main disadvantages for the solid-state fermentation process. In order to develop feasible dry anaerobic digestion processes, it is important to review the optimization techniques and suggest possible areas where improvements could be made. These include reactor configuration, mixing, solid retention time, feedstocks, organic loading rate, inoculation, co-digestion, pretreatment, percolation, additives and environmental conditions within the digester such as temperature, pH, buffering capacity and VFAs concentration **[11]**.

An feasibility study was conducted to provide facts and figures for decision makers in Finland to support the development of the economically and environmentally most promising biogas technology on-farm. The results may encourage on-farm biogas plant manufacturers to develop and market dry anaerobic digestion technology as a complementary technology. This technology may be a competitive alternative for farms using a dry manure chain or even for stockless farms. Up to now, farm scale dry digestion technology does not offer competitive advantages in biogas production compared to slurry based technology as far as only energy production is concerned. However, the results give an overview of existing technical solutions of farm-scale dry digestion plants. The results also show that the ideal technical solution is not invented yet. This may be a challenge for farmers and entrepreneurs interested in planning and developing future dry digestion biogas plants on-farm. The development of new dry digestion prototype plants requires appropriate compensation for environmental benefits like closed energy and nutrient cycles to improve the economy of biogas production. The prototype in Jarna meets the objectives of the project since beside energy a new compost product from the solid fraction was generated on the other hand the two-phase process consumes much energy and the investment costs are high (>2000 € m^{-3} reactor volume) **[12]**.

The technology of dry fermentation can generate energy with communal and agricultural organic waste and biomass. Mixed with substrates from human origin such as yellow water (urine), brown water (faeces, night soil) and to a lesser extent grey water, the aim of a hygienic treatment and additional fertilizer recovery can be realized. Up until now, biogas technology mainly concentrated on “wet fermentation” of agricultural and communal bio-waste as well as sewage sludge, the dry fermentation process can produce methane from biomass, which is not liquid, and in a mixture night soil collected from dry toilette systems. The one staged batch process needs no mixing of biomass during fermentation and no adding of water or liquid compounds, as it is necessary in conventional wet fermentation systems. The usual stirring and pumping do not works well in batch dry fermentation systems. It is especially suited for application in semiarid climates as the water consumption in the process is very low compared to conventional anaerobic digestion systems and can be recovered from the ecological sanitation system **[13]**.

In 1776, Volta discovered the formation of a combustible gas which he related to the quantity of plant material in bottom sediments in lakes, ponds and streams. It was not untill 1868 that Bechamp defined the reaction as a microbiological process. This process, the biological decomposition of organic matter with the liberation of methane gas, is the anaerobic digestion process. Despite the production of methane, with its recognizable value, the utilization of the anaerobic digestion process in waste treatment has been mainly justified on the following: a) sludge volume reduction, b) stabilization, and c) the production of a non-noxious, more acceptable product for final disposal. However, with the increasing demands for fuel, heretofore wastes are being re-examined alternative. Anaerobic digestion as of sewage sludge does not achieve complete decomposition; about 60 – 75 % reduction in volatile solids is generally achieved. Sludge is fed to these digesters at about 5.0 to 10 % solids, thus the residual sludge is about 3 to 6 % solids which may undergo some treatment prior to disposal. In applying this technology to animal wastes the handling and disposal of the residual sludge could be the greatest deterring factor. This investigation examined the anaerobic digestion of animal wastes under relatively dry (solids concentrations greater than 20 %) conditions in a an effort to circumvent the problems of post digestion treatment of digester supernatant, solids concentration and dewatering prior to disposal, and thus enhance the economics of the overall process **[14]**.

Methods and materials:

For dry fermentation, a brick masonry digester has been designed by School of Energy Studies for Agriculture, PAU, Ludhiana. This digester has been constructed in the Field Laboratory of School of Energy Studies. The dimensions of the digester and gas holder are given in the Figure 1.

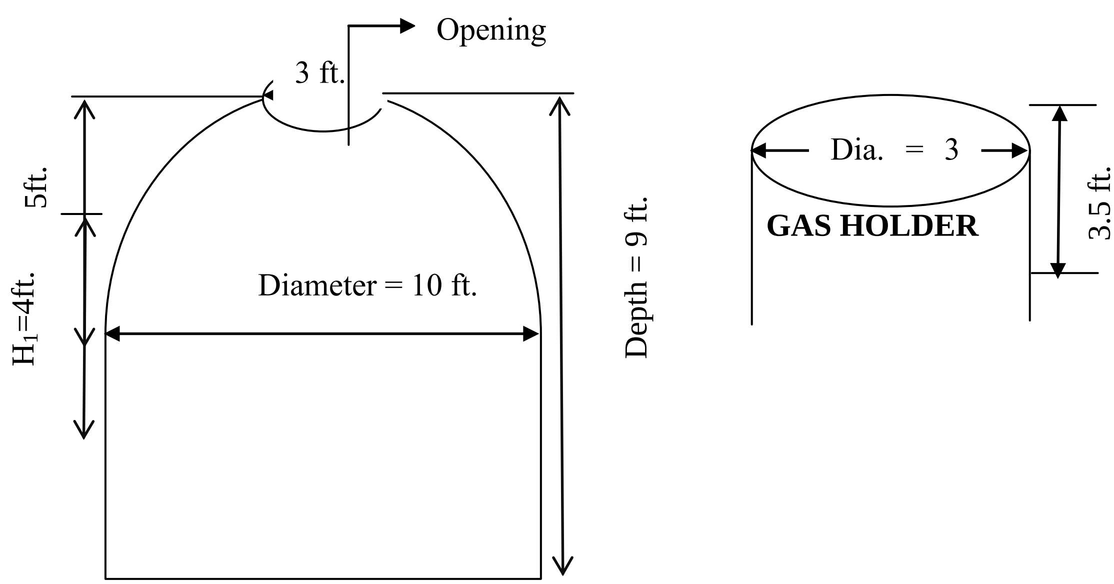

Figure 1: Dimensions of the Digester and Gas Holder.

The feeding in the digester with paddy straw was done in the digester in the month of February, 2012. The feeding in the digester with paddy straw was done in the form of layers of paddy straw and little quantity of cattle dung (Figure 2) till it filled up to top. Then the opening of the digester was closed and made air tight with the help of a cover made up of G.I. sheet. The gas outlet pipe has also been fitted in the cover of the opening. After that water was added in the digester with the help of a pipe connected at the bottom of the digester till the water starts flowing through the gas outlet pipe fitted on the top of the digester. Then adding of the water in the digester was stopped and the bottom pipe was closed so that the water would not come out from the digester. The objective of the adding of water is that paddy straw becomes wet after absorbing water so that anaerobic digestion starts in the digester. After a period of one week, excess water was removed through the bottom pipe. Biogas production starts after a period of about 10 - 15 days which was measured with the help of a steel gas holder connected to the digester through HDPE pipe at the gas outlet pipe. Instrument used for analysing gas content was gas analyzer. Nearly 65 – 70 % of methane composition was anlysed in the biogas.

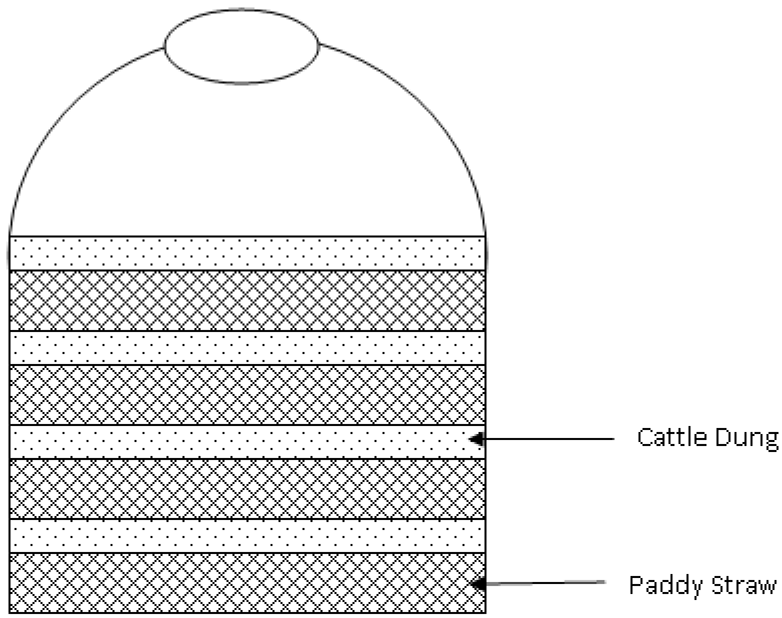

Figure 2: Feeding in the digester with paddy straw and cattle dung in the form of layers.

Results and discussion:

The experiment started in the month of February, 2012 by filling the dry fermentation digester. Measurement of production has been done at the interval of 2 hours at 3 times in a day. It has been seen that in month of April-May the gas production is in range of 7 - 9 m^3/day. This shows the gas production starts from month of February then increases in the month of March and reaches to maximum in the months of April to June.

Conclusions:

By constructing dry fermentation digester and feeding it with paddy straw or residues/woody biomass of other crops or dry leaves along with little quantity of cattle dung, biogas can be produced for approximately 5 - 6 months. This technology will be feasible at the farmer level who can construct two or three digesters for digestion of paddy straw or residues/woody biomass of other crops. Farmers may feed it at the time of availability of material, then he has to charge the digester and it starts producing gas which lasts approximately 5 - 6 months. When the gas starts reducing in first digester then second digester starts operating. In the mean time, when the gas production stops from first digester it will be vacated by moving out digested material which is very much useful as farmyard manure and digester will become ready for reloading.

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