BIOGAS PRODUCTION FROM DE-OILED SEED CAKES OF JATROPHA AND PONGAMIA

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India has a very huge potential of tree-born non-edible oil seeds. The country is endowed with more than 100 species of these oil seeds, occurring in the wild or cultivated sporadically to yield oil in considerable quantities. Attempts are being made to utilize non-edible and under-exploited oils for biodiesel production. The non-traditional seed oils, such as Jatropha curcas, Pongamia pinnata, Pongamia glabra, Madhuca indica, Shorea robusta, Mesua ferra, Mallotus philippines, and Garcinia indica, can be utilized for the purpose of biodiesel production. But, there are critical issues that must be addressed to make biodiesel a techno-economically viable renewable substitute or additive to diesel. The present method of utilization of non-edible oil seeds consumes only extracted vegetable oil for biodiesel production and renders huge amount of unutilized biomass. In general, 50% of the collected fruits of biodiesel resource are seeds (kernels). Out of these seeds, at the most 35% is converted into vegetable oil and the remaining 65% is rejected as toxic de-oiled seed cake. In short, more than 85% of cultivated bio-resource remains unutilized. This toxic seed cake can neither be used as cattle feed nor as a fertilizer. In 2007, the annual production of toxic jatropha (Jatropha curcas) de-oiled seed cake alone was estimated at 60 000 tonnes. However, this could be a big source of bio-energy production from the generated waste. Furthermore, the future scenario of non-edible de-oiled seeds production (such as Jatropha curcas, Pongamia pinnata, and so on) and their utilization for biodiesel production in India is going to increase tremendously with time.

The experimental studies had shown that the direct use of Jatropha curcas press seed cake as animal feed is not advisable due to the presence of toxic compounds such as curcin, a toxalbumin, and other equally harmful substances like phorbolic esters. Hence, the only suggested use of non-edible de-oiled seed cakes is generation of biogas through biomethanation process. Furthermore, the biogas production yield and methane content of biogas are greatly affected by the composition of feed materials in relation to carbohydrate, fat, and protein contents. The oil seed cakes of jatropha and pongamia (Pongamia pinnata) are rich in fat and proteins, and therefore, are considered good feed materials suitable for biomethanation.

Proximate and ultimate analysis of jatropha and pongamia de-oiled seed cakes

Table 1 shows the results obtained from the proximate analysis of de-oiled seed cakes and cattle dung in terms of its moisture, oil, total solids, volatile solids, and non-volatile solid contents.

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Table 1 Physiochemical properties of basic feed materials

Feed material	*Physiochemical properties* Moisture content %	Oil content %	Total solids %	Volatile solids %	Non-volatile solids %
Cattle dung	81.6 (442.5 db)	Nil	18.4	14.4 (78.8 db)	21.2
Jatropha de-oiled seed cake	7.5 (8.1 db)	8.3	92.5	86.4 (93.0 db)	7.0
Pongamia de-oiled seed cake	10.5 (11.7 db)	7.2	89.5	85.3 (94.8 db)	5.2

The proximate analysis of feed materials reveals that the fresh cattle dung has around 81.6% moisture on wet basis (442.5% db [dry basis]) and total solids content of around 18.4% on wet basis. The volatile solids content in fresh cattle dung is found to be about 14.4% on wet basis (78.8% db) and remaining 21.2% as non-volatile solid (ash). The moisture content of jatropha and pongamia de-oiled seed cakes is only 8.1% (db) and 11.7% (db), respectively. The oil content in mechanically expelled de-oiled seed cakes of jatropha and pongamia is found 8.3% and 7.2%, respectively. Total solids content of jatropha and pongamia de-oiled seed cakes is found to be around 92.5% and 89.5% based on wet weight basis. The volatile solid contents of dried jatropha and pongamia de-oiled seed cakes are 93.0% and 94.8%, respectively. It is also evident from Table 1 that the non-volatile solid contents of jatropha (7.0%) and pongamia de-oiled seed cakes (5.2%) is significantly lower than cattle dung (21.2%). The lower value of non-volatile solid in de-oiled seed cakes is due to the absence of lignin in it. However, the cattle dung has high content of lingo-cellulosic material.

The elemental analysis (ultimate analysis) shows that the carbon, hydrogen, and nitrogen contents in jatropha and pongamia de-oiled seed cakes are higher than that of cattle dung (Table 2). The carbon content of the jatropha and the pongamia de-oiled seed cakes are found to be 38.6% and 35.8% higher than that of cattle dung. Similarly, the hydrogen content of the jatropha and the pongamia de-oiled seed cakes are found to be 34.8% and 41.3% higher than that of cattle dung. The nitrogen content of the jatropha and the pongamia de-oiled seed cakes are found to be 148.4% and 254.8% higher than that of cattle dung. However, the C/N (carbon to nitrogen) ratio of the jatropha (12.7) and the pongamia de-oiled seed cakes (8.7) are quite lower than that of cattle dung (22.7).

Figure 1 and 2 present views of jatropha and pongamia de-oiled seed cakes at a soaking time of 24 hours.

Figure 1 24 hour soaked jatropha de-oiled seed cake

Figure 2 24 hour soaked pongamia de-oiled seed cake

It is clearly evident from the figures that the jatropha de-oiled seed cake has remained intact after being soaked in water for 24 hours. However, the observation on pongamia de-oiled seed cake has showed that it became like a paste just after 4–5 hours of soaking in water. Thus, it is expected that the degradation of pongamia de-oiled seed cake will be faster than that of jatropha de-oiled seed cake.

Table 2 Carbon, hydrogen, and nitrogen contents and C/N ratio of the feed materials

Feed material	C (%)	H (%)	N (%)	P (%)	K (%)	C/N ratio
Cattle dung	35.20	4.60	1.55	0.69	1.66	22.7
Jatropha de-oiled seed cake	48.80	6.20	3.85	2.09	1.68	12.7
Pongamia de-oiled seed cake	47.80	6.50	5.50	1.00	1.00	8.7

Preparation of efficient inoculum

A running 20 m^3/day biogas capacity cattle dung digester was selected as an environment. Feeding of cattle dung was stopped continuously for three months to make sure that there is no unprocessed cattle dung present in the digester. Thereafter, feeding of pongamia oil cake with a dilution ratio of 3:1 was carried as per following schedule.

Schedule 1: 8 kg of oil cake substrate (2 kg pongamia oil cake with 6 kg water) with a dilution of 3:1 for five days

No change in drum position was observed for first two days. However, addition of cake substrate was continued. On the third day, there was a small rise (approximately 10 cm), which is equal to a gas volume of 0.90 m^3. The same was continued for two more days and a rapid rise in drum was observed. This showed encouraging results.

Schedule 2: 20 kg of oil cake substrate (5 kg pongamia oil cake with 15 kg water) with a dilution of 3:1 for next 10 days

For the first two days of increased loading, a drop in gas production was observed, as the drum was moving up much slower when compared to the fourth or fifth day. Feeding was continued for few more days and positive results were observed on the third day, with a rapid upward movement of the drum. It reached its highest position (30 cm) on the fifth day and remained almost at the same level for 10 days.

This pattern of biogas production suggested the adaptation of bacteria to the environment offered by new substrates, possibly by developing into a suitable strain. This acclimatization is due to fact that when the concentrations of inhibitory or toxic materials are slowly increased within the environment, many microorganisms can rearrange their metabolic resources, overcoming the metabolic block produced by the normally inhibitory or toxic material. However, sufficient time should be available for this rearrangement to take place under sudden change in environment.

Experimental biogas plant and parameters of biomethanation

Biomethanation study was carried in 20 m^3/day capacity biogas plant by continuous feeding of jatropha and pongamia de-oiled seed cake substrates for 30 days. A schematic diagram of the experimental biogas plant is shown in Figure 3. Figure 4a shows the status of biogas plant before feeding of de-oiled seed cake substrate; the position of floating gas holder is at the lowest. Figure 4b shows the status of the same biogas plant after three days of feeding of de-oiled seed cake substrate; the position of floating gas holder is at the maximum height of reach.

Table 3 shows the daily feeding level of jatropha and pongamia oil cake substrates. Measurements of ambient temperature (°C), substrate temperature (°C), daily biogas production at sewage treatment plant (m^3), methane content (%), carbon dioxide content (%), total volatile solid removal efficiency (%), and specific methane production (m^3/kg TS [total solids] and m^3/kg VS [volatile solids]) were carried out with the use of appropriate instrument and with application of standard procedures and formulae.

Results and Discussion

Daily biogas production

Figure 5 shows the daily biogas yield at STP (sewage treatment plant) and substrate temperature for jatropha de-oiled seed cake substrate

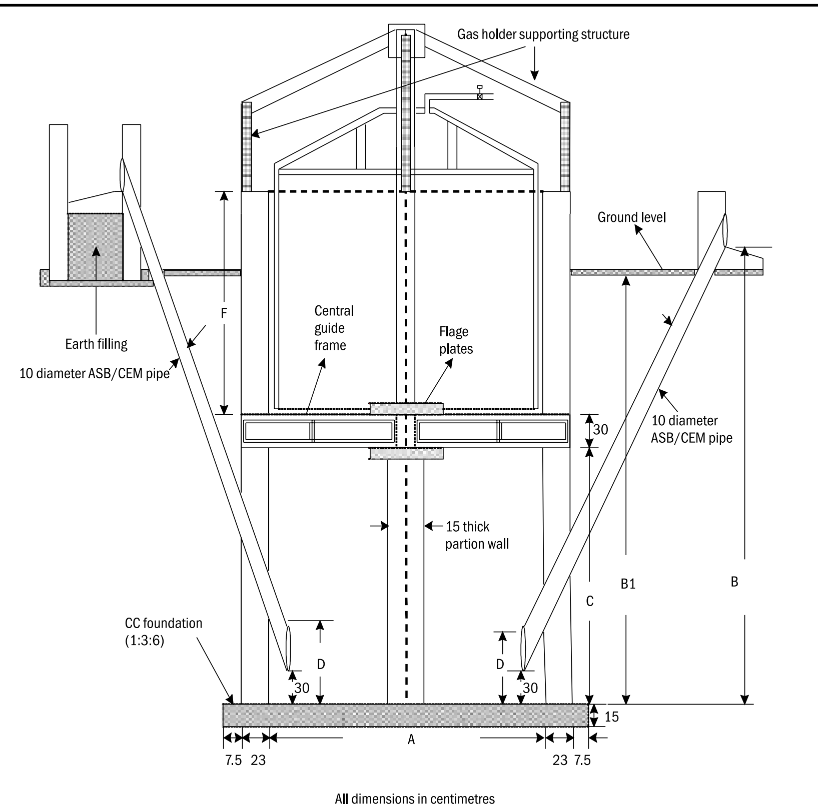

Figure 3 Schematic diagram of 20 m^3/day capacity floating drum biogas plant

Figure 4a A pictorial view of 20 m³/day capacity floating drum biogas plant before start of feeding of de-oiled seed cake

Figure 4b A pictorial view of same biogas plant after three day of feeding of de-oiled seed cake

Table 3 Feeding rate, total solids, and volatile solids concentration in the substrates

	Substrate concentration of daily feed			
	Total solids		*Volatile solids*	
Treatment	*kg/d*	*%*	*kg/d*	*%*
Jatropha de-oiled seed cake substrates JC (4.0 DR, 0% CD)	9.25	18.5	8.64	17.3
Pongamia de-oiled seed cake substrates PC (3.5 DR, 0% CD)	8.95	19.9	8.53	19.0

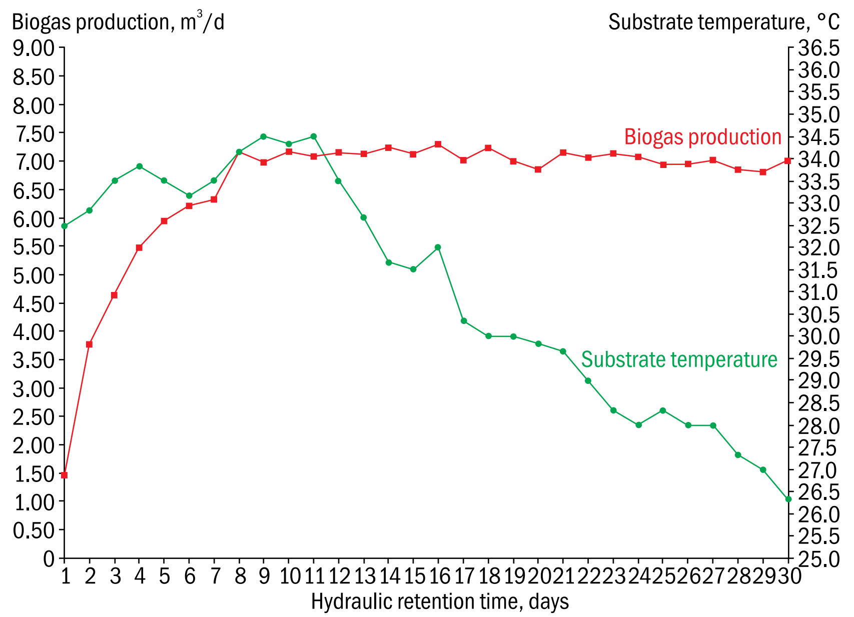

Figure 5 Daily biogas production rate for jatropha de-oiled seed cake substrate

at feeding rate of 9.25 kg TS/day (17.3% VS concentration), daily variation of biogas yield is found to range from 1.5 to 7.3 m³/day over a period of 30 days. Similarly, daily biogas yield at STP at feeding rate of 8.95 kg TS/day and substrate temperature during the period of 30 days for pongamia de-oiled seed cake substrate has been shown in Figure 6. Daily variation of biogas yield was found to range from 1.5 to 8.9 m³/day on pongamia de-oiled seed cake substrate. The average daily biogas production (at STP) during the 30-day period is observed as 6.541 m³/day for jatropha de-oiled seed cake substrate and 7.791 m³/day for pongamia de-oiled seed cake substrate. It is observed that biogas production became almost stable after the eighth day of digestion process.

Methane and carbon dioxide content of produced biogas

The maximum and minimum values of methane and carbon dioxide in jatropha oil cake were found to vary from 68.0% to 60.7% and 32.7% to 29.0%, respectively. The average values of methane and carbon dioxide contents over 30 days of HRT (hydraulic retention time) were found as 66.6% and 31.3%, respectively.

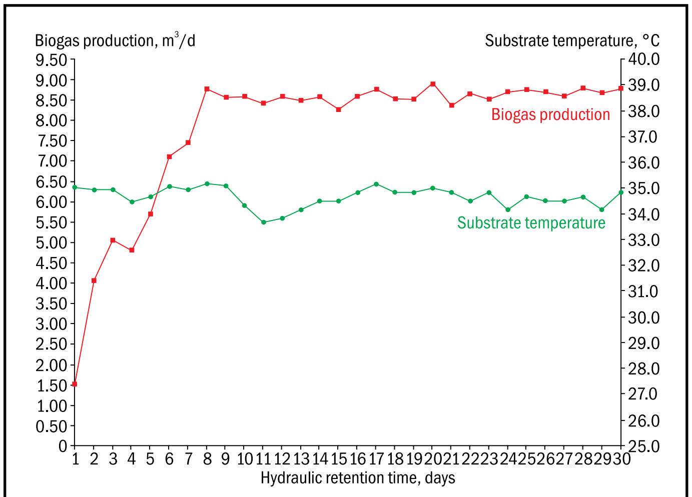

Figure 6 Daily biogas production rate for pongamia de-oiled seed cake substrate

Similarly, the maximum and minimum values of methane and carbon dioxide on pongamia oil cake were found to vary from 65.3% to 56.0% and 38.3% to 31.7%, respectively. The average values of methane and carbon dioxide contents over 30 days of HRT were found as 62.5% and 33.5%, respectively. The observed values of methane concentration in generated biogas showed higher methane percentage than cattle dung generated biogas. This is due to fact that degradation of fat and protein gives more methane content (70%–84%) than 50% on carbohydrate.

Cumulative biogas, methane, and carbon dioxide production yields

Cumulative biogas, methane, and carbon dioxide yields over a 30-day retention period for jatropha oil cake substrate were found as 196.224, 131.258, and 61.271 m^3, respectively. Similarly, the cumulative biogas, methane, and carbon dioxide yields over a 30-day retention period for pongamia oil cake substrate were found to be 233.725, 147.605, and 77.625 m^3, respectively.

Specific biogas production rate

The variation in daily specific biogas yield per unit TS and per unit VS in case of jatropha and pongamia oil seed cake substrates has been shown in Figure 7 and 8. The observed average of specific biogas yields jatropha oil cake substrate over the 30-day HRT period was recorded as 0.598 m^3/day/kg TS and 0.640 m^3/day/kg VS. Similarly, the average value of daily specific biogas yield over a 30-day retention time observed on pongamia oil cake substrate was 0.703 m^3/day/kg TS and 0.738 m^3/day/kg VS.

Specific methane production rate

Figure 9 and 10 show the average production yield of methane from jatropha and pongamia oil cake substrate, respectively. The observed average of specific methane yield with jatropha oil cake substrate over the 30-day HRT period was recorded as 0.394 m^3/day/kg TS and 0.422 m^3/day/kg VS. Similarly, average value of daily specific methane yield over a 30-day retention time observed with pongamia oil cake substrate was found to be 0.427 m^3/day/kg TS and 0.448 m^3/day/kg VS.

Total volatile solids mass removal efficiency

The average value of total volatile solid mass removal efficiency for jatropha oil cake substrate during the entire 30-day HRT period was found to be 59.58%. Similarly, the average value of total volatile solid mass removal efficiency for pongamia oil cake substrate over a period of 30 days was found to be 74.94%.

The study also revealed that the biogas yield per unit of TS and VS was found higher in the case of pongamia oil seed cake substrate than in the case of jatropha oil seed cake substrate. This is in fact due to lower content of non-volatile solids in pongamia oil seed cake (5.2%) than in jatropha oil seed cake (7.0%). The observed results show that the pongamia oil seed cake has higher biodegradability than jatropha oil seed cake, possibly due to higher concentrations of long-chain fatty acid oleates and stearates in the later.

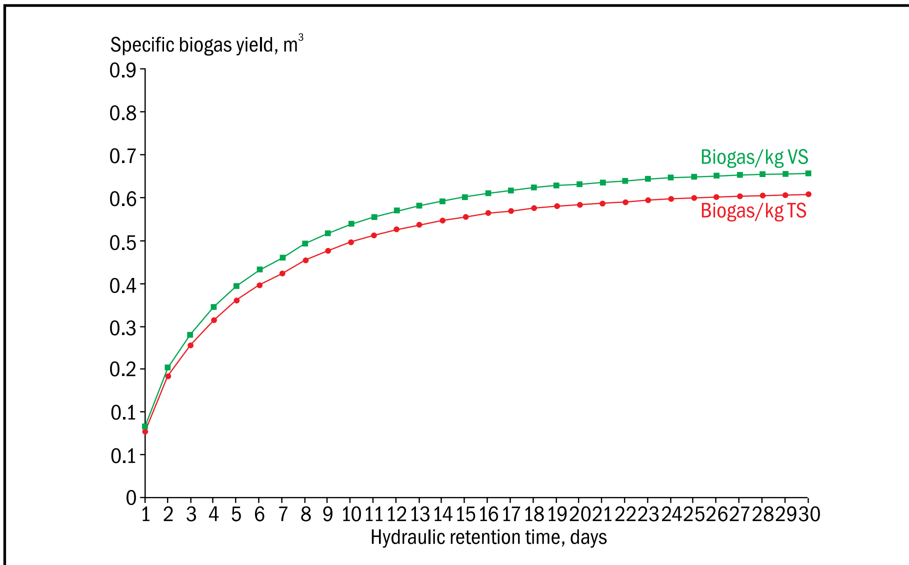

Figure 7 Variation of specific biogas yield for jatropha de-oiled seed cake substrate

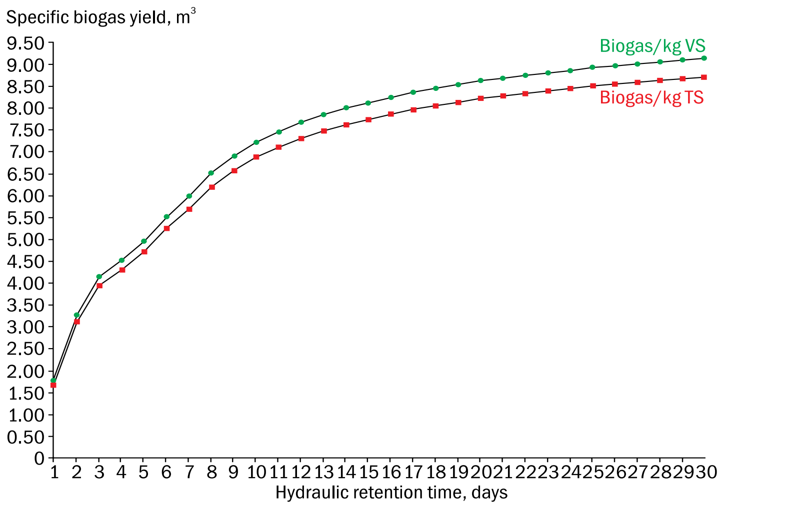

Figure 8 Variation of specific biogas yield for pongamia de-oiled seed cake substrate

and jatropha de-oiled seed cakes shows a dilution ratio of 3:1 and 3.5:1 is appropriate for efficient digestion. Biomethanation of jatropha de-oiled seed cake in 20 m3/day capacity floating drum biogas plant results in an average specific biogas and specific methane production potential of 0.640 m^3/kg VS and 0.422 m^3/kg VS, respectively. The average total volatile solid mass removal efficiency is found to be 59.6%. Whereas, the biomethanation of pongamia de-oiled seed cake yielded an average specific biogas and specific methane production of 0.738 m^3/kg VS and 0.448 m^3/kg VS, respectively. Average total volatile solid mass removal efficiency is found to be 74.9% over a period of 30 days. Thus, the biogas produced from jatropha and pongamia de-oiled seed cakes is much higher than biogas produced from cattle dung and it contains about 15%–20% more methane content.

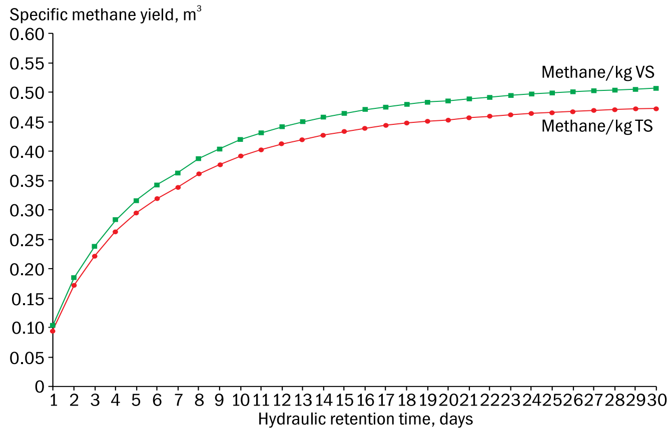

Figure 9 Variation of specific methane yield for jatropha de-oiled seed cake substrate

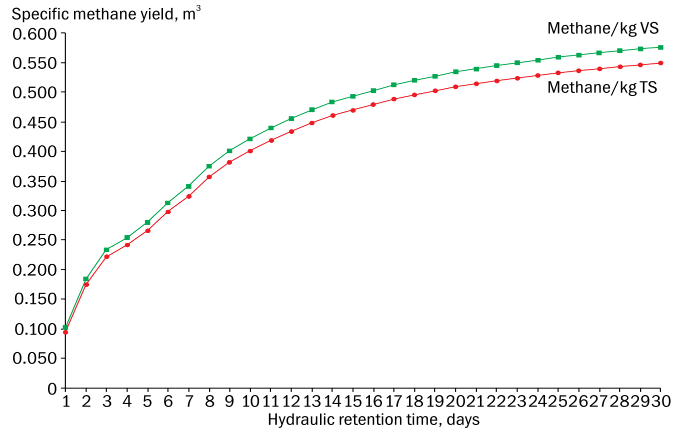

Figure 10 Variation of specific methane yield for pongamia de-oiled seed cake substrate

Conclusions

The outcomes of the proximate and ultimate analysis of feed materials for biomethanation process confirm that jatropha and pongamia de-oiled seed cakes have rich proportionate of volatile solids content. These de-oiled seed cakes have low non-volatile solids content, high hydrogen, and high carbon content as compared to cattle dung. Total solids content of the jatropha and the pongamia de-oiled seed cakes are found to be 92.5% and 89.5% (wet weight basis), respectively. The volatile solids contents of the jatropha and the pongamia de-oiled seed cakes are found to be 93.0% and 94.8% (dry weight basis), respectively. Result shows that the jatropha and pongamia de-oiled seed cakes contain around six times higher volatile solids content than cattle dung. Furthermore, non-volatile solids contents in jatropha de-oiled seed cake (7.0%) and pongamia (5.2%) de-oiled seed cake are significantly lower than cattle dung (21.2%). The carbon content of jatropha and pongamia de-oiled seed cakes are 38.6% and 35.8% higher than that of cattle dung. Similarly, hydrogen content of jatropha and pongamia de-oiled seed cakes are 34.8% and 41.3% higher than that of cattle dung.

Biomethanation study of pongamia

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