

## GASIFICATION OF WASTE OF OIL SEED COLLECTIONS IN A 20 KWe DOWNDRAFT GASIFIER

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### ABSTRACT

Waste of oil seed collections, shells and deoiled cakes from current practice of bio-diesel production from *Pongamia pinnata* seeds, is utilized as a biomass feedstock in a 20 kWe downdraft gasifier. This gasifier is originally conventional wood gasifier. Direct use of this conventional wood gasifier for *Pongamia* shells leads the blocking of remaining gasified shells in grate region of gasifier reactor. This blocking is noticed as the main problem during the gasification of *Pongamia* shells. Gap available between the conical grate (16 cm in diameter) and inner wall of gasifier reactor at grate section is found to be too small for free flow of gasified shells. This conventional wood gasifier is modified by replacing the original conical grate with a new fabricated conical grate (15 cm in diameter). Feasibility of waste of oil seed collections for biomass feedstock of a 20 kWe downdraft gasifier is studied in present work. Performances of gasifier are compared for waste of oil seed collections and wood chips in term of calorific value of producer gas and coefficient of thermal conversion. Calorific value of producer gas from wood, *Pongamia* shells, and *Pongamia* deoiled cakes is 4.48 MJ/kg, 4.28 MJ/kg, and 2.82 MJ/kg respectively. Coefficient of thermal conversion is 0.84, 0.68, and 0.60 for gasification of wood, *Pongamia* shells, and *Pongamia* deoiled cakes respectively. An integrated system involving gasifier, spark ignition engine, oil expeller, and decorticator is tested successfully within 3 hours continuous operation of gasifier on waste of oil seeds collections.

**Keywords:** gasification, waste of oil seed collections, downdraft gasifier.

### INTISARI

*Limbah dari pengolahan buah Pongamia pinnata menjadi bio-diesel dimanfaatkan sebagai bahan bakar biomassa untuk tungku gasifikasi. Limbah ini terutama berasal dari kulit Pongamia dan ampas dari biji yang telah diperas minyak mentahnya. Tungku gasifikasi yang digunakan aslinya adalah tungku gasifikasi untuk biomassa kayu dengan daya keluaran 20 kWe dan bertipe downdraft. Penggunaan langsung tungku ini untuk gasifikasi kulit Pongamia menyebabkan terjadinya penyumbatan laju aliran kulit pongamia di dalam tungku, terutama pada bagian grate. Penyumbatan ini karena jarak antara conical grate dengan dinding sebelah dalam dari tungku terlalu kecil. Selanjutnya modifikasi dilakukan pada tungku gasifikasi dengan menggantikan conical grate aslinya yang berdiameter 16 cm dengan conical grate baru berdiameter 15 cm. Unjuk kerja dari tungku gasifikasi dibandingkan antara gasifikasi biomassa kayu dengan gasifikasi limbah pengolahan Pongamia pinnata dalam hal nilai kalor producer gas dan koefisien konversi kalor. Nilai kalor dari producer gas yang dihasilkan dari gasifikasi biomassa kayu, kulit Pongamia, dan ampas kering Pongamia berturut-turut adalah 4.48 MJ/kg, 4.28 MJ/kg, and 2.82 MJ/kg. Sedangkan koefisien konversi kalor untuk gasifikasi biomassa kayu, kulit Pongamia, serta ampas kering Pongamia berturut-turut adalah 0.84, 0.68, and 0.60. Kesatuan sistem yang terdiri dari tungku gasifikasi yang telah dimodifikasi, motor bensin, oil expeller, dan decorticator berhasil diujikan selama 3 jam secara terus menerus untuk masing-masing biomassa kulit Pongamia, dan ampas kering Pongamia.*

**Kata Kunci:** gasifikasi, limbah pengolahan Pongamia, tungku gasifikasi type downdraft.

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**INTRODUCTION**

*Pongamia pinnata*, one of many sources for Bio-diesel, is a deciduous legume tree that grows to about 15-25 meters in height with a large canopy which spreads equally wide. The leaves are soft, shiny burgundy in early summer and mature to a glossy, deep green as the season progresses. It is a tree that is well-adapted to arid zones and has many traditional uses. It is often used for landscaping purposes as a windbreak or for shade due to the large canopy and showy fragrant flowers. Figure 1 shows the tree and dry seeds of *Pongamia pinnata*.

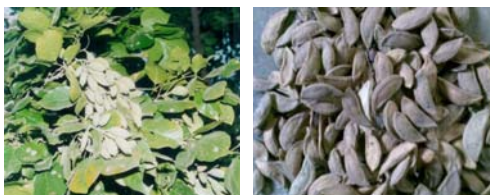


Figure 1. *Pongamia pinnata* tree and dry seeds

Dry seeds of *Pongamia pinnata* have been utilized for bio-diesel production in small scale to medium scale production capacity. Figure 2 shows the process of converting *Pongamia pinnata* seeds into bio-diesel. There are two major drawbacks in current practice of bio-diesel production, which may lead to high cost of bio-diesel. There are wastage of oil seed collections (shells and deoiled cakes) and also extra energy to drive various machines required for bio-diesel production.

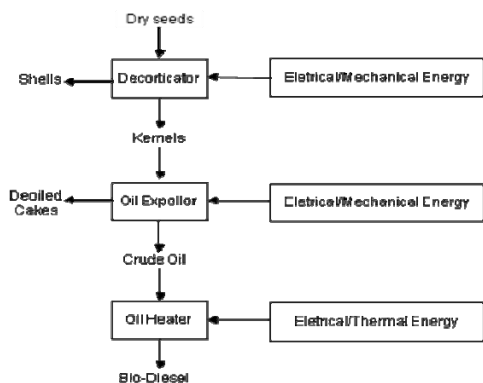


Figure 2. Current practice of Bio-diesel production from *Pongamia* seeds

Considering energy sustainability, a method to utilize shells and deoiled cakes to generate the energy requirement is suggested as shown in Figure 3. Shells and deoiled cakes are utilized for feedstock of gasifier to produce gas called producer gas by means of gasification. The gasifier used is a 20 kWe downdraft gasifier which originally wood gasifier. The producer gas is used to drive a spark ignition engine which supply the extra energy required for decorticator and oil expeller in bio-diesel production. Feasibility of waste of oil seeds collections as biomass feedstock for a 20 kWe downdraft gasifier is studied in the present work. Performances of gasifier are compared for oil seed collections and wood chips in term of calorific value of producer gas and coefficient of thermal conversion.

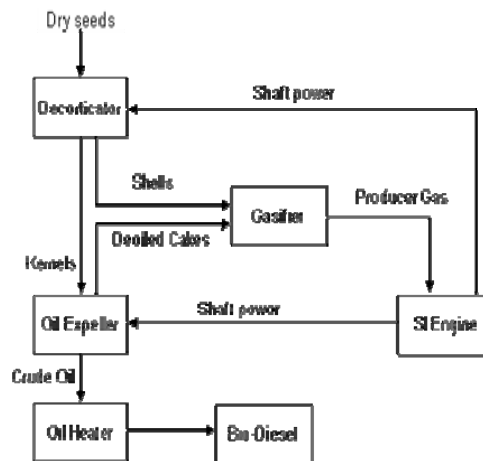


Figure 3. Schematic diagram of utilization of waste of oil seed collections

Mass distribution of *Pongamia pinnata* seeds has been investigated by Subbaro, 2007. Approximately 17.5% only of *Pongamia* seeds are converted into crude oil, the rest shells and deoiled cakes are thrown as a waste. Figure 4 shows a mass distribution of *Pongamia* collections. 50% of kernel is obtained from total mass of *Pongamia* seeds, and remain 50% are shells. From total mass of kernel, only 35% is crude oil and remaining 65% is deoiled cakes. This 82.5% of waste of *Pongamia* collections (50% shells and 32.5 % deoiled cakes) is

a potential source of biomass feedstock for gasifier.

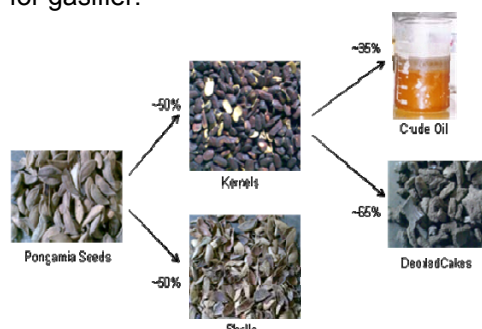


Figure 4. Mass distributions of *Pongamia* collections (Subbarao, 2007)

Energy analysis of shells, deoiled cakes, and bio-diesel from *Pongamia* was also carried out on 1 ton bio-diesel plant of *Pongamia pinnata* (Subbarao, 2007). A bio-diesel plant with 1 ton capacity of bio-diesel requires 1.1 tons crude oil from 6.3 tons *Pongamia* seeds. As shown in Figure 4, related mass distributions of *Pongamia* collections are: 3.15 tons kernels, 2.05 tons cakes, 3.15 tons shells. Energy value of shells, deoiled cakes and bio-diesel is calculated from mass distribution and its calorific value. Total calorific value of shells, deoiled cakes, and bio-diesel is 14.4 MJ/kg, 14.2, MJ/kg, and 38 MJ/kg respectively, total energy distribution of *Pongamia* collections is shown in Table 1. *Pongamia* shells and deoiled cakes have much higher total energy compared than *Pongamia* bio-diesel. Total energy of shells and deoiled cakes is approximately twice of *Pongamia* Bio-diesel. This higher total energy of oil seed collections is potential source for alternative energy by means biomass gasification.

Table 1. Total energy distribution of *Pongamia* collections (Subbarao, 2007)

Pongamia Collections	Total Energy Value
Shells	45.36 GJ
Deoiled Cakes	29.11 GJ
Bio-Diesel	38 GJ

Biomass gasification is a thermo-chemical process of converting solid biomass into combustible gas called pro-

ducer gas by means of partial oxidation carried out in reactor called gasifier (Khisore, 2008). Compared than solid biomass, producer gas has advantages: gases are easy to clean, to transport and to combust efficiently with a low excess of air and little resulting pollution. Further, gases can be burned in an internal combustion engine and can be easily applied in combined cycles (Van Swaaij, 1981).

Typically, in downdraft gasifier sequence process from top to bottom of reactor are drying, pyrolysis, oxidation and reduction. In drying zone, the biomass loses its moisture and is then subjected to pyrolysis resulting in its decomposition into char and volatile. A heterogeneous reaction takes place in the oxidation zone between solid carbonized fuel and oxygen in the air producing carbon dioxide and releasing a substantial amount of heat. In the reduction zone, a number of high-temperature chemical reactions take place yields producer gas.

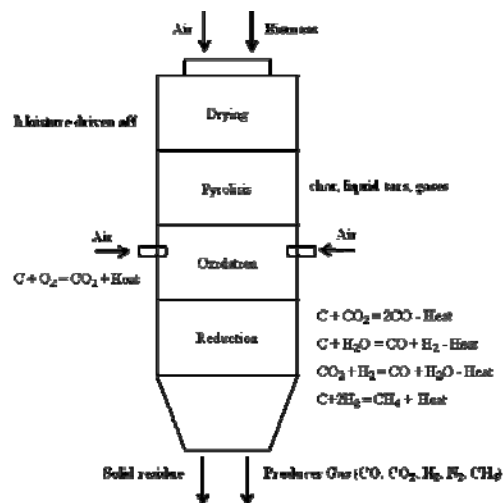


Figure 5. Typically sequence of reaction in downdraft gasifier (Khisore, 2008)

Effect of operating parameter on product gas has been investigated by many researchers. An effect of biomass sources and particles size on producer gas has been reported by Kumar, 2006. The hard wood typically gives a higher calorific value of gas than softwood. Hardwood and ordinary wood shows marginally better gasifier power output as compared to softwood. The percentages of

carbon monoxide, hydrogen, and calorific value of the gas decrease with initial increasing in particle size. Dogru *et al.*, investigated hazelnut shells gasification in downdraft gasifier. The quality of product gas is to be dependent on smooth flow of the biomass in the reactor. Flow characteristics of biomass in the gasifier reactor play an important rule for optimum operation of gasifier.

Experimental Work, A 20 kWe downdraft gasifier used for experimental work in this research is originally wood gasifier. Direct use of this conventional downdraft gasifier for *Pongamia* shells gasification leads the blocking of gasified shells in grate region of gasifier reactor. This blocking is found the main problem of *Pongamia* shells gasification in a 20 kWe conventional downdraft gasifier. It is found that a gap between conical grate and inner wall of gasifier reactor is too small for free flow of gasified shells. Encounter this problem, a new conical grate which diameter of 15 cm is fabricated for replacing an original conical grate (diameter of 16 cm).

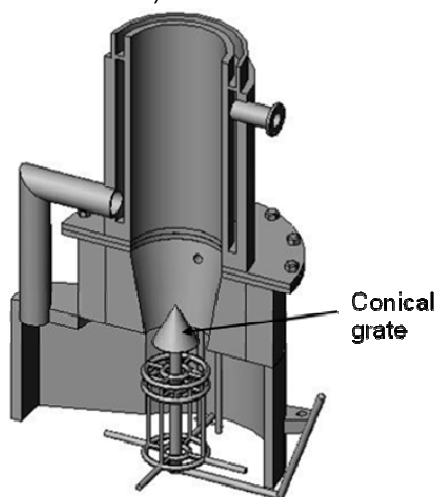


Figure 6. Gasifier reactor and conical grate

Typically in downdraft gasifier, biomass is fed from top of the reactor. Air enters the gasifier in the oxidation zone through air nozzles (tuyer) by means of suction blower. Remains gasified biomass flow through the grate region at the bottom of gasifier. Producer gas flows in the recirculation duct from the bottom of reactor and exits at the top of reactor.

Producer gas is cooled by spray water in two stage cooling unit. Further, gas is cleaned in the coarse sand and fine sand filter from dust and fine particle present in producer gas. Gasifier system consist of reactor, cooling system, cleaning unit, suction blower, water bubbler, burner. U tube water manometers are provided for measurement of pressure at four strategic locations: at the exit of gasifier ( $P_1$ ), at the exit of cooling unit ( $P_2$ ), at the exit of coarse filter ( $P_3$ ), and at the exit of fine filter ( $P_4$ ).



Figure 7. Experimental set-up

Integrated system (gasifier-engine-oil expeller-decorticator) is tested on oil seed collections within 3 hours continuous operation of modified gasifier. Gasifier is run on blower mode before it is switched to the engine. Biomass feedstock is loaded into the reactor. After partially opening a gas valve, suction blower and electric water pump are switched ON. To generate the flame inside a reactor, biomass feedstock is initiated by holding the flame in a form of a blowtorch or wick near to each an air nozzle. After 10-15 minutes the generated producer gas in the burner is lighted. Reading of U tube water manometer at four strategic locations and venturi meter are done during the operation of gasifier. Sample of producer gas is taken after 30 minutes of continuous operation of gasifier. Composition of producer gas is measured using NUCON Gas Chromatograph with Argon

as gas carrier. Gas Chromatograph is calibrated using calibration gas which composition of 10.07% CO<sub>2</sub>, 24.43% CO, 24.98% H<sub>2</sub>, 35.55 N<sub>2</sub>, and 4.97% CH<sub>4</sub>. Composition of producer gas is determined using existing computer software by comparing the peaks area of calibration gas and gas sample.

Using the composition of combustible gas in the producer gas, calorific value of producer gas is then calculated as:

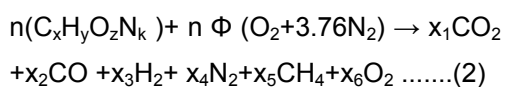
$$CV_g = \frac{(x_2 \cdot CV)_{CO} + (x_3 \cdot CV)_{H_2} + (x_5 \cdot CV)_{CH_4}}{100} \dots(1)$$

Value of x<sub>2</sub>, x<sub>3</sub>, and x<sub>5</sub> are percentage of composition CO, H<sub>2</sub>, and CH<sub>4</sub> respectively, since calorific value of CO, H<sub>2</sub>, and CH<sub>4</sub> are taken from Iyer *et.al*, 2002 in Table 2.

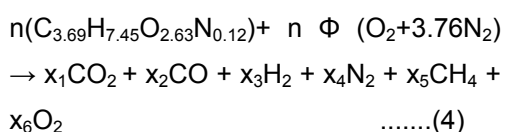
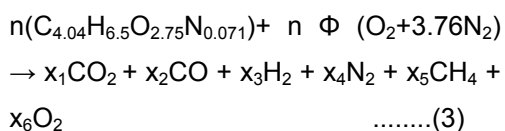
Table 2. Calorific Value of Compound (Iyer, *et al.* 2002)

Compound	CV (MJ/m <sup>3</sup> )
CO	12.71
H <sub>2</sub>	12.78
CH <sub>4</sub>	39.76

Assuming chemical properties of biomass are Carbon, Hydrogen, Oxygen, and Nitrogen, equation of chemical reaction of biomass fuel can be written as (Sonkar *et al.*, 2007):



Chemical reaction for wood chip and oil seed collections are:



The value of n and Φ are determined from Carbon and Nitrogen balance equations. Value of x<sub>1</sub>, x<sub>2</sub>, x<sub>3</sub>, x<sub>4</sub>, and x<sub>5</sub> is taken from composition of CO<sub>2</sub>, CO, H<sub>2</sub>, N<sub>2</sub>, and CH<sub>4</sub> of producer gas respectively.

$$\text{Carbon balance; } n = \frac{x_1 + x_2 + x_5}{x} \dots(5)$$

$$\text{Nitrogen balance; } \phi = \frac{x_4 - \frac{1}{2}n \cdot k}{3.76n} \dots(6)$$

Sequence calculations are used to calculate a coefficient of thermal conversion of gasification. Assuming 100 moles of fuel produce total mass of producer gas, mass of producer gas is:

$$m_g = \frac{\sum x_i MW_i}{100 \cdot n} \dots(7)$$

Where;

$$\sum x_i MW_i = (x_1 \cdot MW)_{CO_2} + (x_2 \cdot MW)_{CO} + (x_3 \cdot MW)_{H_2} + (x_4 \cdot MW)_{N_2} + (x_5 \cdot MW)_{CH_4} \dots(8)$$

Density of producer gas

$$\rho_g = \frac{P_{atm}}{R_g \cdot T} \dots(9)$$

Where:

$$P_{atm} = \text{atmospheric pressure} = 101325 \text{ N/m}^2$$

$$R_g = \text{producer gas constant} = \frac{8315 \text{ J/kmol} \cdot \text{K}}{MW_g}$$

$$T = \text{ambient temperature}$$

$$MW_g = \text{molecular weight of producer gas}$$

$$= \frac{\sum x_i MW_i}{100}$$

Energy released per kilogram of fuel:

$$E_g = \frac{m_g \cdot CV_g}{\rho_g} \dots(10)$$

Coefficient of thermal conversion is defined as the ratio of energy release per kg fuel to the calorific value of biomass feedstock at STP.

$$C_{th} = \frac{E_g \times \left(\frac{273}{298}\right)}{CV_{fuel}} \dots(11)$$

Calorific value of fuel is determined using Bomb Calorimeter. The calorific value of wood chip, *Pongamia* shells, and deoiled cakes was 16.38 MJ/kg, 14.415 MJ/kg, and 14.168 MJ/kg respectively.

### DISCUSSIONS

Calorific Value of Producer Gas, Figure 8 shows the calorific value of producer gas from gasification of different biomass. *Pongamia* shells produce a producer gas with slightly lower calorific value compared to wood. While *Pongamia* deoiled cakes produce a producer gas with moderate lower calorific value compared to wood. Producer gas from wood, shells and deoiled cakes has calorific value of 4.48 MJ/kg, 4.28 MJ/m<sup>3</sup> and 3.85 MJ/m<sup>3</sup> respectively. Although waste of oil seed collections produces the producer gas with lower calorific value, but biomass of waste of oil seed collections is by product of bio-diesel production from *Pongamia pinnata*.

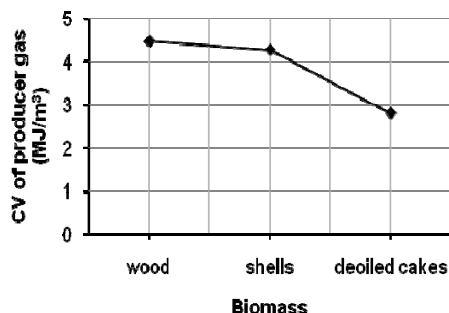


Figure 8. Calorific value of producer gas from different biomass.

Coefficient of Thermal Conversion of Gasification, look at Figure 9 shows the coefficient of thermal conversion of wood, *Pongamia* shells, and *Pongamia* deoiled cakes. Coefficient of thermal conversion is defined as the ratio of energy release per kg of biomass to the energy contain in biomass. Coefficient of thermal conversion of wood, *Pongamia* shells, and *Pongamia* deoiled cakes is 0.84, 0.68, and 0.6 respectively. As energy released per kg of shells and deoiled cakes is lower than energy released per kg of wood, hence lower coefficient of thermal conversion of shells and deoiled cakes.

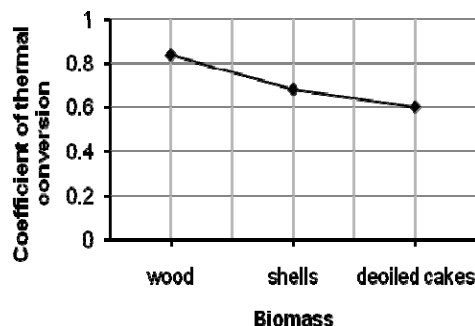


Figure 9. Coefficient of thermal conversion of different biomass gasification.

Coefficient of thermal conversion of *Pongamia* shells increases for gasification using modified gasifier. No blocking is found in the grate region of gasifier reactor. Shells in the reactor move smoothly. This smooth flow of shells in the gasifier reactor during gasification increases the quality of producer gas, hence improves the coefficient of thermal conversion of shells gasification using modified 20 kWe downdraft gasifier.

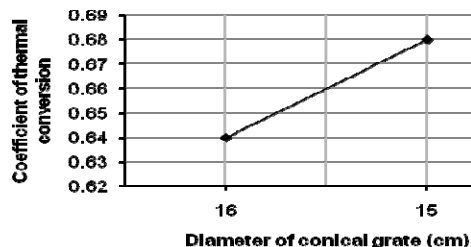


Figure 10. Coefficient of thermal conversion *Pongamia* shells gasification for different diameter of conical grate

Flow Characteristics in the Gasifier System, Static pressure at four strategic locations across the gasifier system at any interval times is shown in Figure 11. The integrated system is tested on oil seed collections within 3 hours. Static pressure at the reactor exit and fine filter exit is almost constant during 3 hours continuous operation of gasifier. Pressure at cooling exit and coarse filter exit is constant within 2 hours, then increases after 1 hour continuous operation of gasifier. The increasing in static pressure at cooling exit and coarse filter exit is still within the limit of maximum operating static pressure of the gasifier.

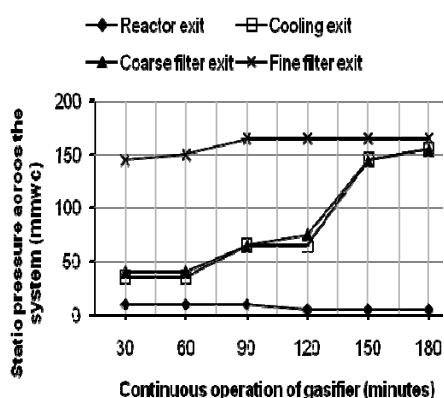


Figure 11. Static pressure at four strategic locations during testing of integrated system on oil seed collections.

### CONCLUSION

Waste of oil seed collections of *Pongamia pinnata* (shells and deoiled cakes) is feasible for biomass feedstock of a 20 kW downdraft gasifier which is originally wood gasifier. This downdraft gasifier is modified with a new conical grate which diameter of 15 cm for encounter the blocking of gasified shells in the grate region. Although calorific value of producer gas from gasification of waste of oil seed collections is slightly lower than calorific value of producer gas from wood gasification, as well as coefficient of thermal conversion for oil seeds collections, but an integrated system is tested successfully within 3 hours continuous operation of modified gasifier on oil seeds collections without any problems in the systems.

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