

Chapter 2: Literature Review

Generating energy from biomass gasification is not new technology. It was initiated in 1800s, generally at that time it was only restricted to cooking and lightning purpose. As the time progresses research scholar around the globe investigated the new possibilities of the innovation in this domain. Plasma gasification and supercritical gasification are one the innovation in this domain. Researcher are also experimenting on biomass gasifier to increase its efficiency and optimizing the operating parameters of gasifier. In this present study comprehensive review on the investigation done by different researchers on downdraft gasifier has been presented incorporating feedstock used in the study, descriptions of gasifier, input parameters and output results. It is depicted in table 2.1

Table.2.1 Comprehensive Summary of research progress in Downdraft Gasifier

Biomass	Gasifier description	Experimental condition	Research findings
Mixture of charcoal and coconut shell [79]	<ol style="list-style-type: none"> 1. Throat less reactor was used with an internal diameter of 20 cm and an insulator thickness of 5 cm 2. Central body of the gasifier was made-up using 0.3 cm thick mild steel sheet with 30 cm inner diameter 3. It also consisted of four separable sections. 4. Three stage air supply system was cast-off 	<ul style="list-style-type: none"> • Variable ports of air supply with variable air flow rate • Primary air supply port (180 l/min), secondary air supply port (120 l/min) and tertiary air supply port (200 l/min) • Coconut shell consumption = 17.16 kg/hr • Charcoal consumption = 0.25 kg/hr 	<ul style="list-style-type: none"> • Lowest tar content observed was 28 mg N/m³. • Calorific value of PG enhances at excess air flow rate. • Maximum temperature at second stage combustion is 913 °C. • Overall system efficiency is 11.69% • Net heating value of producer gas is 4.86 MJ N/m³.

Cashew nut shell, Babul wood, Groundnut shells briquettes and Ground nut shell [80]	<ol style="list-style-type: none"> 1. Open core throat less reactor was used with thermal capacity of 623 MJ/h 2. Main body of the gasifier was made up of mild steels (I.S 2062) ceramic wools insulator with thickness of 5 cm. 3. Hopper induced with manual loading was used as feeding system. 4. Ash removal unit was manual rotatory type and electric suction blower was used for gas discharge. 	<ul style="list-style-type: none"> • Fuel consumption rate (kg/hr) of babul wood (41.1), groundnut shell briquettes (53.2), groundnut shells (37.66) and cashew nut shells (47) • Specific rate of gasifications = 160 kg/h m². • Average gas flow rate = 100-130 Nm³/hr. 	<ul style="list-style-type: none"> • Heating value of producer gas varies in the range of 4.3-4.8 MJ N/m³. • Cold gas efficiency varies in the range of 64-70% • Downward flow problem in groundnut shell was observed during gasification because of low density (66.47 kg/mm³).
Cashew nut shell [49]	<ol style="list-style-type: none"> 1. Throat less and open core reactor was used having an insulator thickness of 5 cm. 2. Capacity of feedstock was 60 kg/h. 3. 4 nozzles were used for the stream of air. 	<ul style="list-style-type: none"> • Variable flow rate of Producer gases (61, 87, 130) m³/hr. • Biomass consumption rate (23, 35, 47) kg/hr. 	<ul style="list-style-type: none"> • The maximum flame temperature achieved was 848°C at 130 m³/hr flow rate of gas. • Optimum discharge of producer gas is 130 m³/hr. • Optimum specific rate of gasification is 167 kg/hr • Maximum gasification efficiency is 70% • Calorific value of PG enhances with increasing discharge of producer gas • The variation in flame temperature gets stabilized within the range of 820-880°C. • Specific gasification rate at 4.5 and 5.5 gas flow rate is 220 and 270 kg/hm² respectively. • Gasification efficiency at 4.5 and 5.5 gas flow rate is 65.96 and 68.31%. • Pocking and ramming should be done for constant flow of feedstocks in the gasifier.
Jatropha seed husk [48]	<ol style="list-style-type: none"> 1. Without throat type reactor was used 2. Hopper induced with manual loading was used as feeding system 3. Nozzle present at oxidation zone and at suction blower were used as air supply system 4. Rotating grate coupled with manually handled screw conveyors acts as a discharge system. 	<ul style="list-style-type: none"> • Variable gas flow rate = 4.5, 5.5 m³/hr. • Biomass consumption rate = 1.8, 2.2 kg/hr. 	<ul style="list-style-type: none"> • The variation in flame temperature gets stabilized within the range of 820-880°C. • Specific gasification rate at 4.5 and 5.5 gas flow rate is 220 and 270 kg/hm² respectively. • Gasification efficiency at 4.5 and 5.5 gas flow rate is 65.96 and 68.31%. • Pocking and ramming should be done for constant flow of feedstocks in the gasifier.

Acacia wood [46]	<ol style="list-style-type: none"> 1. Throat type reactor was used with thermal capacity of 75 Kw. 2. Gasifier contained recirculating ducts and double layers thermal insulator. 3. 3 tuyers at throat section and t suction blower were used as air supply system. 4. Grate connected with lever mechanism and ash pit were used as discharging system 	<ul style="list-style-type: none"> • Variable air flow rate = (4, 14, 24, 34) g/s. • Variable gas flow rate = (0-30) g/s. • Pressure drop was measured along all the variables. 	<ul style="list-style-type: none"> • The extinguished bed depicts much higher pressure drop as compared to freshly charged gasifier bed. • Flow rate of PG has relationship with gasifier temperatures. The temperatures of gasifier at PG flow rate of 0.9 g/s is elevated than that at producer gas flow rate of 8 g/s and 7 g/s. • Maximum temperature occurs in oxidation zone. The temperature of oxidation zone enhances from 1115 K to 1168 K for flow rate of PG from 7 g/s to 9 g/s
Dalbergia sisoo [15]	<ol style="list-style-type: none"> 1. Imbert type reactor was used associated with water sealed top cover 2. Cumulative height was 110 cm wherein altitude of oxidation zone, pyrolysis zone were 5.3 cm and 10 cm respectively 3. Diameter of reduction zone and pyrolysis zone were 15 cm and 31 cm 4. Fire bricks were cast-off for insulation at the oxidation zone 5. Grate coupled with lever mechanism and ash pits associated with water tray were used as discharge system 	<ul style="list-style-type: none"> • Air discharge= (1.80-3.40) m³/hr. • Equivalence ratio = (0.1- 0.4) • Biomass consumptions rate = (1.0-3.70) kg/hr 	<ul style="list-style-type: none"> • The optimum equivalence ratio reported by author is 0.205. • The calorific value, maximum pyrolysis section temperature and the oxidation zone temperature at ER = 0.205 are 6.25 MJ/Nm³, 550°C, 1050°C respectively. • Biomass consumptions rate are inversely proportional to moisture content and is directly proportional to air flow rate. • Increasing ER, the production rate of PG enhances. • The magnitude of cold gas efficiency is 0.25 at ER=0.17 and the effect of ER on cold gas efficiency is relatively lower for higher value of ER • The fraction of CO and H₂ depicts up and down trends exactly opposite to that of N₂ and CO₂.

Wood chip and Hazelnut shell [41]	<ol style="list-style-type: none"> 1. Throat type reactor was used having cumulative height of gasifier was 109.5 cm. 2. Central body of gasifier was made of stainless steel (AISI 310 S) having thickness 0.3 cm and a diameter of 30 cm. 3. It also have a provision of air jacket outside oxidation zone and this is because of preheating of gasified air. 4. Three nozzles having diameter of 1 cm placed above 5 cm above the grate and a blower having power of 250 W. 	<ul style="list-style-type: none"> • Variation of ER = (0.15-0.55) • Variation of heating value (MJ/Nm³) with respect of time 	<ul style="list-style-type: none"> • Optimum equivalence ratio reported by the author is 0.35 • The maximum heating value of producer gas obtained is 5.5 MJ/Nm³ at the optimum value of ER. • No complications of tar obstruction and agglomeration throughout gasifications are observed. • Tar contents was not quantitatively evaluated, but with semis quantitative assessments. • Tar content in PG is elevated for gasification of hazelnut shells than that for wood chips gasification
Corn straw [40]	<ol style="list-style-type: none"> 1. Throat-less type reactor was used with an internal diameter of 30 cm and a height of 85 cm. 2. Centerline nozzles and bustle pipes on reactor body was used for air supply system. 3. Rotating grate composed from perforated cast irons and ash hoppers was used for discharging system. 	<ul style="list-style-type: none"> • Variable Biomass feeding rate (kg/h): 8.30, 8.80, 9.40, 9.10, 9.50, 9.60, 9.90 • Variable Air flow rate (Nm³/h): 10.70, 12.90, 15.70, 17.80, 21.40, 24.30, 28, 50 • Variable ER: 0.18, 0.21, 0.24, 0.28, 0.32, 0.36, 0.40 	<ul style="list-style-type: none"> • Temperature of the gasifier enhances with increase in equivalence ratio. • Mole fraction of CO₂ declines and mole fraction of CO, H₂ and CH₄ rises at equivalence ratio from 0.18 to 0.32 • Mole fraction of H₂, CO, and CH₄ drops off at ER greater than 0.32 • Highest lower heating value of gas obtained was 5.390 MJ/m³, gas yield was 2.14 Nm³/kg biomass at ER of 0.28–0.32.
Cornstalk [42]	<ol style="list-style-type: none"> 1. Reactor was throat-less form and composed of Carbon steels and refractories insulators with thickness of 15 cm 2. Internal diameter of reactor was 42 cm and a height of 85 cm. 	<ul style="list-style-type: none"> • Variable feeding rate (kg/hr) = (5.8 – 9.3) • Variable equivalence ratio = (0.18-0.37) • Variable air flow (Nm³/hr) in first and second stage = (0.9 – 1.72) 	<ul style="list-style-type: none"> • A consistent and high temperature profile can be obtained at 3 stage air supply leads to enhanced tar cracking • Bridging and Channeling problems can be countered using three stage air supply in the gasifiers.

	<ol style="list-style-type: none"> 3. Three-stage supply system was fabricated 4. Separated hopper coupled with a screws conveyors was used as an air supply system. 5. Rotating grate composed of cast iron and screw conveyors acts as a discharging system. 	<ul style="list-style-type: none"> • Air flow in third stage = (4.1-8.5). 	<ul style="list-style-type: none"> • Lower heating values (LHV) of PG declines with enhancing rate of biomass feeding. • The magnitude of Tar concentration elevates with increasing feeding rate of biomass. • Optimum feeding rate of biomass and equivalence ratio reported by the author are 7.50 kg/hr and 0.25–0.27, respectively
Eucalyptus [44]	<ol style="list-style-type: none"> 1. Reactor was throat less type with cumulative height of 106 cm. 2. Main body was composed of carbon steels and refractories wall having inner radius of 15 cm. 3. Grate coupled with vibrator and ash pit were for discharge system. 4. In order to avoid channeling and bridging problems, conical bunker was used for feeding system. 5. Double stage air supply was used. 	<ul style="list-style-type: none"> • Variable air flow rate = (16-24) Nm³/hr. • Variable air ratio = (0-100)% with interval of 20% • Variable equivalence ratio = (0.303, 0.279, 0.289) 	<ul style="list-style-type: none"> • The pyrolysis zone temperature increases after the injection of 2nd stage air. • The temperatures of a pyrolysis and oxidation area are 685°C and 750 °C, respectively achieving at optimised air ratio of 80%. • The increasing pyrolysis zone temperature leads to decreasing tar content because of tars cracking. • Composition of PG is 19.20% CO, 1.30% CH₄, 17.14% H₂, and 14.22% CO₂ and a lower heating value of 4.74 MJ/Nm³ observed at optimised air ratio of 80% and total air of 20.0 Nm³/h. • 87.0% tar decline and 29.90% particle/dust lessening in producer gas can be achieved at the same condition.
Oil palms fronds [82]	<ol style="list-style-type: none"> 1. Reactor was throat type with 5 cm thickness of refractory cement insulator. 2. Internal diameter of reactor was 30 cm with height of 110 cm and a throat diameter of 15 cm. 3. Tuyers inlet and pipe along vertical axis of 	<ul style="list-style-type: none"> • Discharge of air (L/min) • Temperatures (°C) • Magnitude of moisture contents. 	<ul style="list-style-type: none"> • Quality of producer gas enhances as CO increased from 22.49% to 24.98%, CH₄ from 1.98% to 2.87% and H₂ from 9.67% to 13.58% due to preheating of air. • Producer gas yield, carbon conversion efficiency and cold gas efficiency also gets

	<p>the gasifier was used as an Air supply system:</p> <p>4. Electric heater was used for discharging heated air into the gasifier.</p>		<p>enhanced due to preheating of air.</p> <ul style="list-style-type: none"> • The temperature of drying, pyrolysis and oxidation zone increases due to preheating but temperature of reduction zone declines. • Producer gas compositions gets varied amongst feedstocks with moisture content 10% to 20% with preheated air gasification.
Peanut shell [47]	<ol style="list-style-type: none"> 1. Reactor was throat built type with the measurement of throat diameter is 7 cm, a height of reduction zone is 20 cm and a cumulative height of reactor was 61 cm. 2. Producer gas system was re-circulating in nature. 3. Hopper and screw conveyor was used for feeding system unit 	<ul style="list-style-type: none"> • Variable gas flow rate (m^3/hr) for non- heat and heat were 1.62, 2.34, 3.06 and 3.54 • Variable biomass consumption rate (kg/hr) = 3.00, 3.16, 3.27, 3.60 	<ul style="list-style-type: none"> • The thermal integrated unit decreases magnitude of tar content in PG thus enhances efficiencies. • Heat generated from PG is employed for increasing temperature of pyrolysis region and a feedstocks in separated hopper (thermal integrated unit). • The carbon conversions efficiency with heat recovery unit enhanced up to 5.75% at the optimal condition ($3.06 \text{ m}^3/\text{hr}$ discharge of air) • The optimum magnitude of global specific gasifications rate was $58.75 \text{ kg}/\text{h m}^2$. • The optimum magnitude of cold gas efficiency and lower heating values were 60.65% and $3.920 \text{ MJ}/\text{m}^3$.
Furniture's wood waste and Wood chips [83]	<ol style="list-style-type: none"> 1. Shape of Reactor was conical with an uppermost radius of 30 cm, a bottommost radius of 10 cm (cone's slant 60°) and a height of 250 cm. 2. Nozzles at 15 cm above throat and blower used as an air supply system. 3. Hopper coupled with manual loading acts as a feeding system: 	<ul style="list-style-type: none"> • Variable equivalence ratio = 0.25, 0.3, 0.35, 0.4, 0.45 	<ul style="list-style-type: none"> • Higher Heating Value (HHV) of PG has direct relationship with ER from 0.26 to 0.38, but reduces at equivalence ratio greater than 0.38. • Optimum value of CO and CH_4 are acquired at ER 0.38. • Average magnitude of HHV of PG is $5.340 \text{ MJ}/\text{Nm}^3$. • Cold gas and overall efficiencies are found to be

	4. Grate and ash box were used for discharging unit.		80% and 10–11%, respectively.
Rice husk pellet [53]	<ol style="list-style-type: none"> 1. Throat-less type reactor was used for the experiment 2. Pneumatic conveyor was used for feeding system 3. Open top of gasifier was used for air supply system. 4. Rotating grate along with pneumatic conveyor was used for discharging unit. 	<ul style="list-style-type: none"> • Variable fuel feed rate (kg/hr) of rice husks and rice husks pellets were (40-45) and (50-60) correspondingly. • Variable air flow rate (Nm³/hr) of rice husks and rice husks pellets were (60-75) and (50-60) correspondingly. • Variable excess air ratio (0.4-0.7) 	<ul style="list-style-type: none"> • The oxidation zone temperature of gasification is 600-850°C. • The heating value of the synthetic gas produced from rice husks pellets depicts higher value of 1314 Kcal/Nm³ than rice husk. • The cold gas efficiency of rice husks and rice husks pellet was calculated as 60% and 70%.
Jatropha shell [84]	<ol style="list-style-type: none"> 1. Throated type reactor was used. 2. Hopper was used for feeding system 3. Single stage with inclined inlets acts as an air supply unit. 4. Rotating grate and ash pit was responsible for discharging unit. 	<ul style="list-style-type: none"> • Variation of (PG/BM) with respect of time were (2.04-2.39) • Variation of (A/PG) were (0.5-0.67) • Variation of (A/F)_o were (1.29-2.01) • Variation of equivalence ratio (0.24- 0.37) 	<ul style="list-style-type: none"> • Heating value of PG was obtained 5.2 MJ/m³ • Gasifier thermal efficiency comes out to be 64.8% • Gasifier coupled with engine unit efficiency comes out to be 24.50% • Clinker accumulation on the grates are detected during Jatropha shells gasification. It may be due to long residence period of ash (20–25 min) on the grate
Miscanthus and Bioethanol waste pellet [9]	<ol style="list-style-type: none"> 1. Reactor was built as throat-less type with a cumulative capacity of 50 kW. 2. Diameter of reactor was 0.24 m with a height of 2 m 3. Hopper with manual feeding acts as a feeding system 4. Four-stage tuyers was used as air supply system. 5. Grate and ash pit were used for discharging unit. 	<ul style="list-style-type: none"> • Pellet feeding rate (kg/hr) of DDGS pellet, E-on miscanthus pellet and simple miscanthus pellets were 9.0, 9.50, 7.50 • Discharge of air (L/min) of DDGS pellets, E-on miscanthus pellet and simple miscanthus pellet were 130, 180, 130 	<ul style="list-style-type: none"> • The highest efficiency was observed with Miscanthus pellets in which cold gas efficiency was 30% and carbon conversion efficiency was 47% • Combustion rate was affected by the low durability pellet having high amount of fine particles. • Gasifier temperature increases due to high concentration of fine particles in pellet which leads to the additional contact area obtainable .

		<ul style="list-style-type: none"> • Equivalence ratio = 0.2, 0.28, 0.27 	<ul style="list-style-type: none"> • The quality of producer gas was enhanced due to high temperature which eventually led to melting of ash.
Sesame wood waste [85]	<ol style="list-style-type: none"> 1. Throat type reactor was used with a cumulative height of 110 cm. 2. Hopper was used for feeding system. 3. Gasification agents was air and steam in which air was supplied to oxidation zone and steam was introduced into gasifier from the top of reduction zone. 4. Shaking grates and Bottom water tray was responsible for discharging 	<ul style="list-style-type: none"> • Variable moisture contents (0.0150-0.0420) • Variable steam to biomass ratio (0.70-1.21) • Variable ER = (0.1288-0.303) 	<ul style="list-style-type: none"> • Feedstock consumption rate are inversely proportional to moisture content. • Optimum value of equivalence ratio reported by the author is 0.24 • Flow rate of air is directly proportional to biomass consumption rate. • Hydrogen yield in producer gas increases by the use of steam. • Model prediction data are not equivalent with experimental data in the present investigation.
Black pine pellet [50]	<ol style="list-style-type: none"> 1. Reactor was throat type composed of Stainless steels. 2. Inner diameter of reactor was 10.23 cm with a cumulative height of 100 cm. 3. There are 3 unit ignition ports available on the reactor body 4. The gasifier can be able to operate in downdrafts or updrafts mode. 5. Stainless mesh grate was used for discharging unit. 	<ul style="list-style-type: none"> • Feeding mass (kg/15 min) = 0.50 • Steady state feeding mass (kg/20 min) = 0.250 • Air discharge(L/min) = 20.0 • Preliminary packed = mass of sample (kg) = 0.50 	<ul style="list-style-type: none"> • Downdraft mode is found to be more stable than updraft mode • Unstable composition of producer gas was investigated in the downdraft mode as gasifier temperature is unbalanced in downdraft mode. • Tar content was found to be less in downdraft mode. It may be due to tar cracking.

After performing extensive literature survey it has been found that there is no author has concluded with the cumulative effect of engine input variable for an optimum response of performance and emission together. Hence, there is essential to study biomass and low-grade coal-gasified PG coupled with an internal combustion engine and provide the optimum engine

input parameters for improved engine performance and operation. Because, if the blended form of chemical energy is available for power generation in an engine and its operating variables are not optimized, there will be a reduction in power and increment in fuel consumption and emission. Concerning these aspects, in the present study, following research gap has been concluded. From the extensive literature review It has been observed that very few experimental analysis was performed which integrates the gasifier with VCR IC engine. It can be also be inferred from the literature survey that most of the previous studies only investigated the conventional operating parametric impact of gasifier on the gasification performance. There is an urgent need for the optimal range of operating parameters wherein the gasifier should operate and delivers the most optimum response in terms of high quality of syngas. It was also being observed that very few experimental investigations integrated with simulation work have been reported on the influence of variable gasifier equivalence ratios on the gasifier performances, and the subsequent effect on fuel consumption at different load and compression ratio on VCR CI engine. The latest design of gasifiers which include the integration of gasification process and gas conditioning in one reactor, plasma gasifier are very captivating and can act as a promising opportunity in the future perspective of nonconventional energy generation