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HUNGARIAN LOW RANK COAL GASIFICATION AND SINGLE LINE MULTI-STAGE GASIFICATION: SHORT REVIEW

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Abstract: Presently, the thermochemical process is widely used in the utilisation of fossil fuels. In which, gasification processes are the most attractive solutions for the cleaner utilisation of coal. One of the main challenges is the development of the reactor considering a better conversion efficiency. In this paper, the background research shows that there is a field of research with a gap within the gasification of low rank coals, especially regarding the fine-tuning of the synthesis gas composition within the process. There are several research focusing on multistage gasifiers, however, these approaches mainly focused on the multi-stage gasification of biomass fuel to enhance the quality of synthesis gas, especially in the reduction of tar content to use in combustion process as internal combustion engine or combined heat and power plant. In addition, using air as reactant showed the poor result in the ratio of H_2/CO for further direct application in the chemical process.

Keywords: thermochemical processes, gasification process, coal gasification, synthesis gas

INTRODUCTION

Nowadays, coal has the largest proved reserves among fossil fuels in the world [1]. However, it is mainly distributed in several countries, such as United State of America (23.3%), Russian Federation (15.2%), Australia (13.9%), China (13.2%), and India (9.9%). Although, renewable energy (excluding hydro) had the highest growth in 2019. However, the world primary energy was still driven by fossil fuel resources, accounted for 84.3%. In which, the share of coal was around 27% of the total primary energy.

In future, coal will still play an important role in the scenarios of power fabrication to 2040, approximately 28% of the global primary energy [2]. As an expectation, the existing reverses of coal will be suitable for 153 years at the same today's consumption rate. It is higher than that of oil and natural gas reverses, 50.6 years and 52.5 years respectively [3].

Generally, the low-rank coals (LRCs) comprise of sub-bituminous coal and lignite (brown coal), well-known from the early-stage formation of coalification. These coal types constitute about one-third of the global proven coal reservoir [1], [4], mainly in the United State of America, European countries, Australia, and several Asian countries. LRCs are characterised as lighter, higher moisture content, and lower heating value than that of high-rank coals (bituminous and anthracite) [5]. The total Hungarian coal proved reservoir has been about 2909 million tonnes, till the end of 2019 [1]. In which, the LRCs are accounted for nearly 90.5% of the total Hungarian coal reservoir. These coal types (brown coal and sub-bituminous) are distributed mainly in Trans-Danubian and North-East coal basin in Hungary [6]. The properties of these LRCs are very high sulphur and moisture content, as well as very

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low heating value [7]. The higher moisture content leads to the higher challenging level in the application of LRCs. The high moisture content results in lower heating value, it leads to lower the thermal efficiency of the plant, higher CO_2 emission, as well as higher construction and operation cost [8]–[16]. Furthermore, the cost of long transportation and storage of LRCs would be increased due to its high moisture content. In the other hand, the LRCs have a strong tendency for self-ignition during hauling and storage period as a result of the high oxygen functional group [10], [11], [13]. The other disadvantage of LRCs is the higher ash content, it also increases the cost of operation in the post-treatment processing [17].

However, the LRCs have certain advantages compared to other high-rank coals. It can be seen clearly that the first one is the lower cost of the open-cut LRCs mining and the inexpensive energy source [8], [10], [12]. Moreover, the higher inherent contents of volatile, alkali and alkaline earth metals make the higher reactivity for the LRCs [13], [18], [19]. It leads to the better application of LRCs in the pyrolysis and gasification process. Currently, the LRCs is mainly used in the thermal power plant for the local electricity generation [20]. However, the coal utilization is growing as a key in chemical industries, as raw material for coking, methanol, ammonia, dimethyl ether, olefin, etc. [21].

It cannot be denied that the electricity generation has been highly depended on fossil fuels, like coal, at least until the half of this century. But on the other hand, the use of traditional technologies in coal power generation will lead to even higher emission levels. Clean coal technology (CCT) could be one of the solutions for this conflict. The meaning of CCT is a broad term. Various combinations of CCTs depend on the way of definition and utilisation in each country around the world. Generally, CCT will cover one or more criteria in the following conditions: (i) the power plant is more efficient than a conventional coal-fired power plant through different operation parameters – temperature and pressure, or (ii) the plant has a facility that captures and stores carbon dioxide in the operation period, or (iii) the plant can reduce localised pollutants, as particulate matter (PM_{10}, $PM_{2.5}$), Nitrogen oxide NO_x, sulphur oxide SO_x, and heavy metals [22].

CCT could be grouped into two main categories *(Figure 1)*, environmental protection and global warming [23]. Environmental protection includes NO_x combustion and flue gas treatment. Global warming is divided into high-efficiency cycle, CO_2 capture, and biomass co-combustion technology. Currently, coal gasification is considered as the most interesting attraction of CCTs. Gasification is one of the thermochemical conversions processes, besides the combustion and pyrolysis process [24], in which using heat and gasifying agents to convert carbon content into gas. As shown in *Figure 2*, the different products are gained from the application of these processes. The application of gasification and pyrolysis products have higher flexibility than that of the combustion process.

1. LITERATURE REVIEW

1.1. Principle of gasification process and gasifiers

In general, gasification is a thermochemical process, in which using heat and gasifying reactants convert the carbon-based material (coal, biomass, MSW, natural gas, natural oil…) into a synthesis gas. The gasifying reactants react with solid chars, tar matters, and gases to generate synthesis gas. In the literature, several researchers have referred to air, O_2-rich gas, steam, CO_2, super-critical water, and their mixture as gasifying reactants. The main reactions of the gasification process can be listed as [25]:

Combustion reaction:

$$C + \frac{1}{2}O_2 \rightarrow CO \ (\Delta H_{298} = -111 \ kJ/mol) \tag{1}$$

$$CO + \frac{1}{2}O_2 \rightarrow CO_2 \ (\Delta H_{298} = -283 \ kJ/mol) \tag{2}$$

$$H_2 + \frac{1}{2}O_2 \rightarrow H_2O \ (\Delta H_{298} = -242 \ kJ/mol) \tag{3}$$

Boudouard reaction:

$$C + CO_2 \leftrightarrow 2CO \ (\Delta H_{298} = 172 \ kJ/mol) \tag{4}$$

Water gas reaction:

$$C + H_2O \leftrightarrow CO + H_2 \ (\Delta H_{298} = 131 \ kJ/mol) \tag{5}$$

Hydrogasification reaction:

$$C + 2H_2 \leftrightarrow 2CH_4 \ (\Delta H_{298} = -75 \ kJ/mol) \tag{6}$$

Water gas shift reaction:

$$CO + H_2O \leftrightarrow CO_2 + H_2 \ (\Delta H_{298} = -41 \ kJ/mol) \tag{7}$$

Steam methane reforming reaction:

$$CH_4 + H_2O \leftrightarrow CO + 3H_2 \ (\Delta H_{298} = 206 \ kJ/mol) \tag{8}$$

Hydrocarbons reforming reaction [26]:

$$C_nH_m + 2nH_2O \rightarrow nCO_2 + \left(2n + \frac{m}{2}\right)H_2 \ (\Delta H_{298} > 0) \tag{9}$$

Tar reforming reaction [26]:

$$Tar + n_1H_2O \rightarrow n_2CO_2 + n_3H_2 \ (\Delta H_{298} > 0) \tag{10}$$

Generally, the air and O_2-rich gas are used in the partial combustion stage to produce the heat required for the gasification process *[Equations (1), (2), (3)]*. Therefore, steam and CO_2 are two main gasifying reactants during the gasification process. The Boudouard reaction *[Equation (3)]* is an endothermic reaction and it takes place at above 700 °C [27]. The water gas reaction *[Equation (5)]* and steam methane reforming *[Equation (8)]* also are endothermic reactions. They are promoted at a higher gasification temperature. The hydrogasification reaction *[Equation (6)]* and water gas shift reaction *[Equation (7)]* are exothermic reactions. High-pressure is required for the hydrogasification reaction, therefore this reaction is not considered in the experiment with a near ambient pressure in the reactor. While the water-gas shift reaction *[Equation (7)]* results in the increase of H_2/CO ratio in the synthesis gas.

The feedstocks of gasification process differ highly in their chemical, physical and morphological properties. Therefore, the universal gasifier that is able to handle all or most feedstocks types, does not exist, and may not exist in the foreseeable future [28]. In the gasifier, all the gasification reactions are taken place in high temperature and normal pressure (ambient pressure) or high pressure. The high-pressure operation associated with the introduction of the feedstocks into reactor.

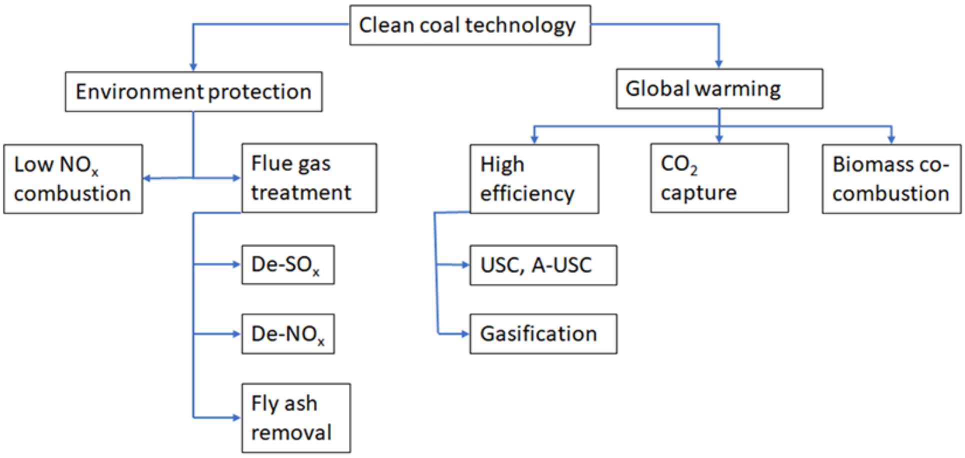


Figure 1
Clean coal technology [23]

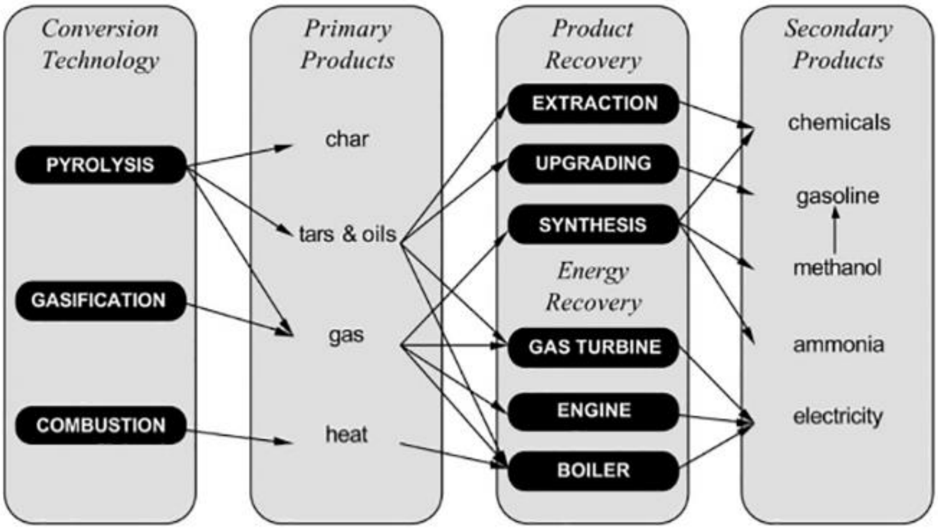
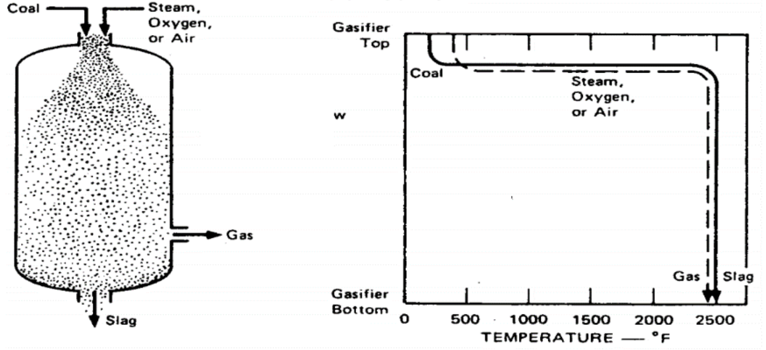


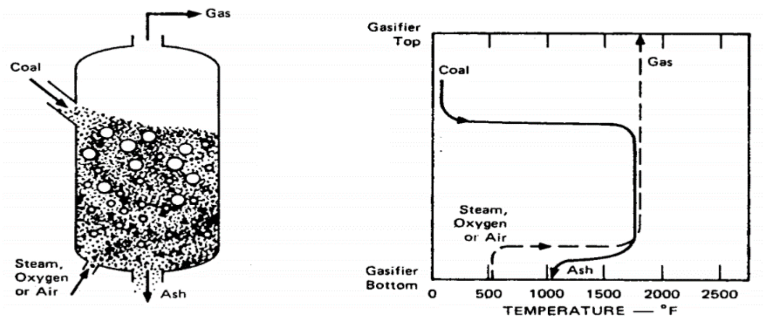
Figure 2
Thermochemical processes and products [24]

To select a gasifier, the properties need to be considered in order to ensure stability, gas quality, efficiency, and pressure losses only within certain ranges of the fuel characteristics, which are [28]: (i) energy content, (ii) moisture content, (iii) volatile matter production, (iv) mineral matter content – ash forming propensity, (v) ash chemical composition and reactivity, (vi) feedstock reactivity, (vii) feedstock size and size distribution, (viii) bulk density of the feedstock and (ix) feedstock propensity for char formation.

Entrained flow



Fluidized bed



Fixed bed

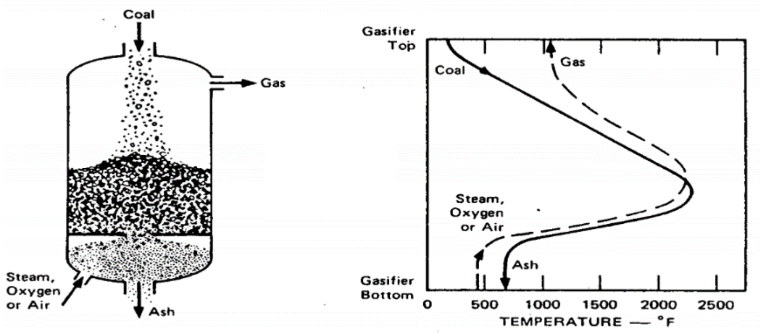


Figure 3
The configuration of gasifier types [29]

In general, the gasifier can be classified into three principal configurations, entrained flow, fluidized bed, and fixed bed gasifier (moving bed). *Figure 3* presents the configuration of gasifier types in the transportation of gas and particles, and the temperature also [29]. In the entrained flow gasifier, the fuels and gasifying agents are fed into gasifier from the top at elevated pressure. This gasifier type has the largest capacity, but the requirements of feeding particle size and operating temperature are very high, therefore the input energy is higher than that of other types. In fluidized bed gasifier, the fuel-gas mixing is suspended in the reaction zone, but it leads to the carbon conversion problems. This gasifier type is highly recommended for biomass due to the low average tar production [30]. The main problem of fixed bed gasification is the tar production in syngas in contrast, there are many advantages of fixed bed gasifier overs the other types, such as low requirement thermal input, low gas exit temperature.

An updraft fixed bed gasifier is a vertical reactor where the movement of fuel and syngas is opposite *(Figure 4-a)*. The fuel is fed from the top of the gasifier, whereas the oxidizers come from the bottom, and the fuel gas is collected in the top of gasifier also. The gasifying agents enter in the bottom of gasifier through a grate, it contacts firstly with the hot ash and oxidant zone above the grate, and then to reduction zone. The heat requirement for pyrolysis and drying process is supplied from the hot production gas. Therefore, the syngas composition contains the water vapour from the drying process, tar and by-products from the pyrolysis process. These do not pass the gasification process for thermal cracking, therefore the separation from the syngas will create addition operating cost [31].

In the downdraft moving bed gasifier *(Figure 4-b)*, the fuel is fed in the top of the reactor and the gasifying agent is injected in the oxidation zone while the production gas is collected at the bottom of gasifier. The pyrolysis gas passes co-currently through the oxidation and gasification zones, so this leads to the lower tar content but will also reduce the heating value of the syngas [32]. The other drawback of this gasifier type is the syngas leaves the reactor at elevated temperature therefore the efficiency of the gasification process will decrease [31].

The gasifying agent is entered at the middle of the reactor and the syngas outlet is built on the opposite side in the cross draft fixed bed gasifier *(Figure 4-c)*. There are several limitations of this gasifier, such as low produced gas quality, high level of tar content, high level of CO_2 concentration, and high exit temperature of the syngas [31].

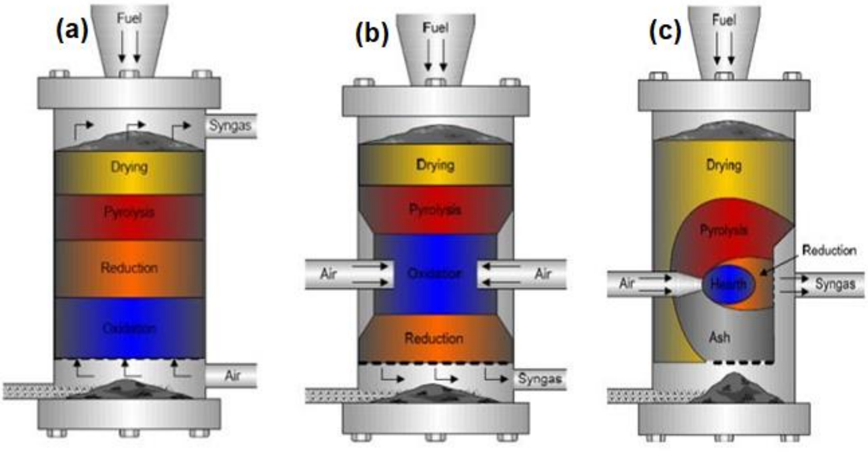


Figure 4
Fixed bed gasifier [29]

1.2. End-use of produced gas

The produced syngas composition has the most important role in the final application. The composition produced syngas depends on various factors, including feedstock, gasifier type, and gasification operation parameters (e.g., temperature, pressure, reactant type, etc.). The produced gas can be listed as low heating value gas, medium heating value gas, high heating value gas, and synthesis gas [28]:

- Low heating value gas (producer gas) is a gaseous product of the gasification process, in which air is used as a reactant. Typically, the heat value gas varies in a range of 5÷11 MJ/m^3. Using air as a reactant, the nitrogen content presents from less than 33 V% to slightly more than 50 V%. The produced gas is suitable for combustion process.
- Medium heating value gas produces typically by the steam gasification. Its heating value ranges from 11÷20.5 MJ/m^3. Medium heating value gas is considerably more versatile than low heating value gas. It can be burned directly in the boiler and used in the combined power cycle. But medium heating value gas is especially able to synthesize methane (by methanation), longer chain hydrocarbon derivatives (by Fischer-Tropsch synthesis), methanol, and a variety of synthetic chemical products.
- High heating value gas is also known as synthetic natural gas or substitute natural gas (SNG). It is essentially pure methane.
- Synthesis gas (syngas) is a mixture of mainly carbon monoxide (CO) and hydrogen (H_2), which is the product of high-temperature gasification with the reactants as steam and/or oxygen. After cleaning-up, syngas can be used to produce organic molecules such as synthetic natural gas (SNG-methane) or liquid biofuels such as synthetic diesel (via Fischer-Tropsch synthesis).

1.3. Gasification of Hungarian low rank coals

In Hungary, coal is used mainly in the energy sector, shared 17% of national gross electricity generation in 2010 [33]. However, the investigation in the gasification of Hungarian brown coal is being an attractive field in term of the multi-proposed transformation for cleaner production in recent years.

A. Pettinau et al. [7] carried out the experiments of Hungarian brown coal in both of lab-scale and pilot-scale gasifier. In this study, the brown coal was collected in North-East coal basin in Hungary, with 13.78÷20.48 MJ/kg of lower heating value (LHV) and 31.1÷38 wt%. of carbon content in dry basis sample. The lab-scale gasifier was made of resistant steel pipe within 80 mm of inner diameter and 1200 mm of effective length in the University of Miskolc. The gasifier temperature was set at 800 °C by an external electrical heater. The steam flow rate was supplied at the rate of 5.2 g/min and pressure at 0.3 MPa after drying and devolatilization process. In each experiment, there was 2.5 kg of coal fed into the gasifier. During the steam gasification period, the average gas production was 0.3 m^3/h. The H_2 content varied from 60 to 70 V/V%, while the CO and CO_2 content were below 20% in gasification time. With the mixing of oxygen and steam, the oxygen was fed from the bottom of gasifier with the flow rate at 300÷350 dm^3/min. It was observed that the CO content was dominant between 35 and 40 V% and following by H_2 at around 35 V%. Regarding to the pilot gasification process, it carried out in Sotacarbo pilot platform, in Italy. With the experiments in air blown up-draft gasifier, there were about 19-23 Nm^3/h of raw synthesis gas produced within the feeding rate at 11 kg/h of Hungarian brown coal. The results were observed that the cold gas and hot gas efficiency were reached the high level, approximately 95-99% of coal gas efficiency and 93-97% of hot gas efficiency. Furthermore, this research noted that the fixed bed gasifier is more suitable for the Hungarian brown coal type in the energetic term.

L. Bokányi et al. [6] investigated the plasma gasification conditions with/without air addition. The gasifier has the 38 cm of inner diameter and 52 cm of height with a capacity of

30 kVA. The Borsod brown coal was used in these experiments, with very high moisture content at 27 wt%. and the LHV at 15.44 MJ/kg. The results were presented that the H_2 and CO content were higher in case of using O_2 addition than that of without O_2. It led to the higher heating value of synthesis gas when the O_2 was used as a reactant in plasma gasifier. It was also noted that there was possibility to convert 97.2% of the carbon content into the carbon monoxide in the synthesis gas. This study concluded that the Borsod brown coal can be efficiency transformed into the synthesis gas within the plasma gasifier with O_2 addition.

1.4. Single line multi-stage gasification process

The superiority of the gasification process is the high flexibility in the end-use application of produced gas for chemical process. Within the chemical synthesis process, the quality of produced gas is one of the most important things besides the chemical synthesis conditions as catalysts, temperature, pressure etc. The quality of synthesis gas can be listed as the components and composition of gases, as well as the impurity contents like particle and tar. In which, the fine-tuning of the H_2/CO ratio is the key challenge during the gasification process. The essential ratio of H_2/CO for the direct application in several chemical synthesis processes is presented in *Table 1*.

Table 1

Chemical synthesis processes with H_2/CO ratio [34]

Product	**Basic chemical reactions**	**H_2/CO ratio**
FT liquid fuels	$n\,CO + 2n\,H_2 \rightarrow C_nH_{2n} + n\,H_2O$ $n\,CO + (2n+1)\,H_2 \rightarrow C_nH_{2n+1} + n\,H_2O$	2.0 2.1
Methanol	$CO + 2\,H_2 \rightarrow CH_3OH$	2.0
Ethanol	$2\,CO + 4\,H_2 \rightarrow C_2H_5OH + H_2O$	2.0
Higher alcohols	$n\,CO + 2n\,H_2 \rightarrow C_nH_{2n+1}OH + (n-1)\,H_2O$	2.0
Dimethyl ether	$2\,CO + 4\,H_2 \rightarrow CH_3OCH_3 + H_2O$	2.0
Acetic acid	$2\,CO + 2\,H_2 \rightarrow CH_3COOH$	1.0
Ethylene	$2\,CO + 4\,H_2 \rightarrow C_2H_4 + 2\,H_2O$	2.0
Ethylene glycol	$2\,CO + 3\,H_2 \rightarrow C_2H_6O_2$	1.5
Acetic anhydride	$4\,CO + 4\,H_2 \rightarrow (CH_3CO)_2O + H_2O$	1.0
Ethyl acetate	$4\,CO + 6\,H_2 \rightarrow CH_3COOC_2H_5 + 2\,H_2O$	1.5
Vinyl acetate	$4\,CO + 5\,H_2 \rightarrow CH_3COOCHCH_2 + 2\,H_2O$	1.25

Regarding to the control of H_2/CO ratio during gasification process, there are several effective ways in changing the gasification parameters (temperature, pressure, etc.), the selection in reactant types and its ratio, the utilisation of catalysts, and the gasifier setup modification. The multi-stage gasification is well-known as a promising approach in the enhancement of process efficiency and quality of product gas as well. In the gasification process, the sub-processes include drying, devolatilization, partial oxidation, and reduction process. In multi-stage gasification, the separation or combination of these sub-processes are highly depending on the fuel properties such as reactivity, ash content, sulphur content, and volatile content [35]. The multi-stage gasification can be commonly categorised as single-line and double-line process, are shown in *Figure 5* [35]. In the single-line process, there is only one stream of mass (solid and gas products) that go through a number of reactors in series or a reactor with multi-injection of reactant. In the double-line process, the mass stream will be separated into at least two partial lines which flow through several reactors in parallel. In this section will be focusing on the progress of the single-line multi-stage fixed bed gasification process.

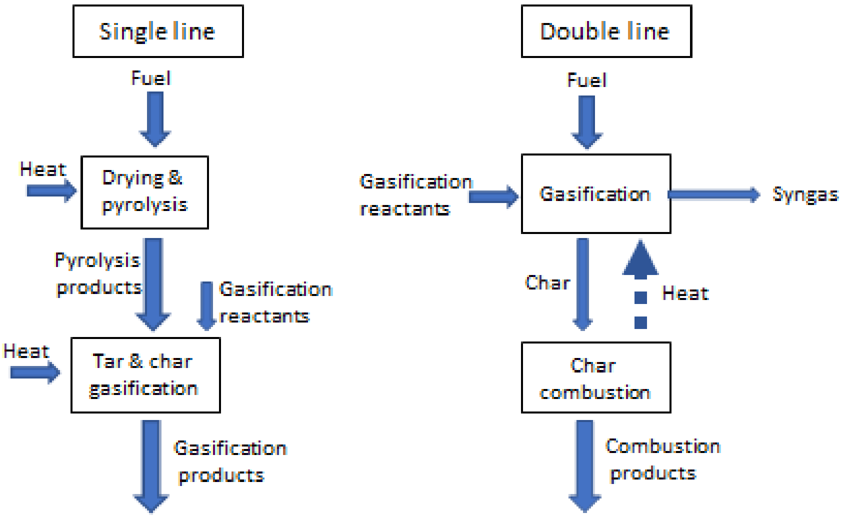


Figure 5
The single line and double line multi-stage gasification [35]

Generally, there are two main methods in the single-line multi-stage gasification process, the physical and non-physical modification. In which, the physical modification aims to separate and optimize the sub-processes (drying, devolatilization, combustion, and gasification) for higher gasification efficiency. While the non-physical method is carried out by the separation of air distribution during the gasification process. There are two or more air intakes used in the non-physical method, called as multi-air stages gasification process.

With the many benefits in the operation and efficiency of the process, the down-draft gasifier was used in several types of research in the multi-air stages gasification process. These research can be categorised into double air stages [36]–[42] *(Figure 6-a)* and three air stages *(Figure 6-b)* [43] autothermal gasification process. In most cases, one of the air intakes was used to hold the partial combustion in the double-air gasification process. The other air intake would be introduced in the pyrolysis and/or drying zone to increase the efficiency of the pyrolysis process by the partial oxidation of organic matter.

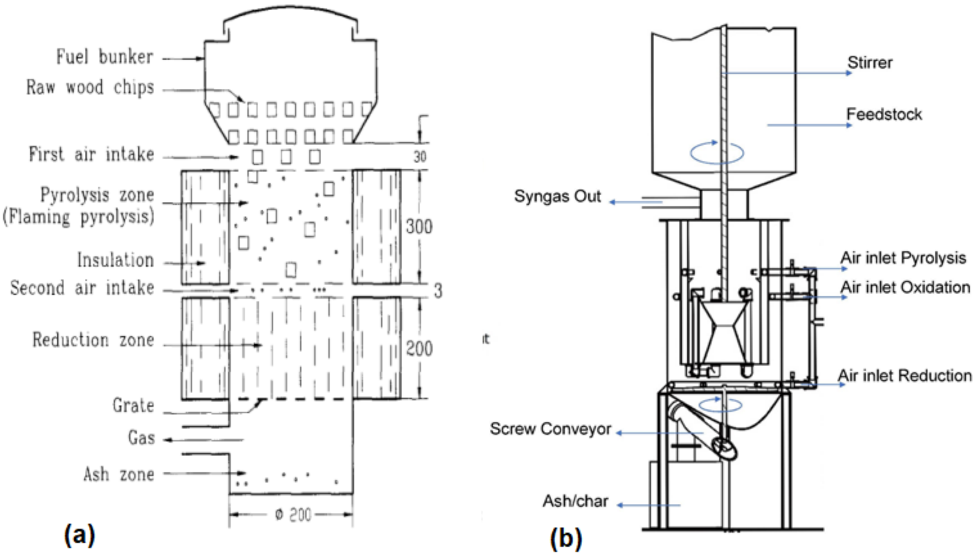


Figure 6
Multi-air stage gasification system [36] [43]

T. Bui et al. examined the double-air stage in a down-draft throatless autothermal gasifier with biomass fuel [36]. Besides the main air inlet for partial combustion zone, the other air inlet was established for a flaming pyrolysis process. This study indicated that the tar content in double-air gasification process was about 40 times lower than that in single stage air gasification. Regarding to the synthesis gas composition, the main components were carbon-based gases (CO and CO_2) due to using air as a reactant in the gasification process. The H_2/CO ratio were 0.64 and 0.61 in two-stage and single-stage, respectively. The effects of airflow rate and its distribution in air intakes were investigated in a down-draft gasification process of biomass with 0.3 m of internal diameter and 1.06 m of height [39], [42]. With the airflow rate range of 16÷24 Nm^3/h and the air distribution at 0, 40, and 80%, these investigations showed that the gasification efficiency was increased with the proper ratio of airflow rate and the air distribution as well. This could be clearly seen in the reduction of tar and particle content in synthesis gas. With airflow rate at 20 Nm^3/h and the air supply for pyrolysis stage at 80% in compared to airflow rate for partial combustion stage, the tar and particle content was from 54.25 to 102 and 4 mg/Nm^3, respectively. While that were 418.95 and 146.03 mg/Nm^3 with 0% of air distribution [39]. These researches also revealed that CO and H_2 were dominant components in synthesis gas, counting for around 19.04 and 16.78 V% [42]; 19.2 and 17.14 V% [39]. The mixture of the air/oxygen and steam in the double air-stage autothermal gasification process helped to increase in the H_2 concentration, even though the steam used in the experiment was not superheated [38], [40]. The mean value of H_2 concentration was in a range of 18.4 to 34.3 V% with the mixture reactants of air/oxygen and steam, while that was only 16.3 to 17.2 V% in case of air gasification [38]. Saleh et al. examined the municipal solid waste gasification process in three air stages gasifier with an additional air stage in the reduction zone [43]. The air intake in the reduction zone increased the gasification performance in compared to the single stage condition. Regarding to synthesis gas composition, the CO and H_2 concentration firstly improved with an increase in air flow rate in reduction zone. However, it was a reduction trend for the further increase in air flow rate in reduction zone due to the higher combustion rate. In addition, the three-air stage also produced the synthesis gas with the lower tar content at 57.29 mg/Nm^3 in compared to 146.98 mg/Nm^3 in single air stage gasification.

Two-stage is a concept used as the physical modification in the single-line multi-stage gasification process [44]–[47] *(Figure 7)*. In which, the sub-processes (such as drying, pyrolysis, partial combustion, and reduction) are mechanically separated to optimise each stage for higher efficiency in the whole gasification process. In the two-stage gasification process, the drying and pyrolysis process are carried out in an allothermal auger reactor. The necessary heat for the pyrolysis process is provided from the flue gas of combustion process (such as internal combustion engine or burner) of synthesis gas. The second stage is an autothermal fixed bed reactor, including partial combustion and reduction process. After the pyrolysis process, the partial combustion of pyrolysis gas and char take place with the right selected ratio of reactant in the free space above the hot char bed. Finally, the produced gas is passed through the hot char bed at the bottom of the reactor for further reaction. Using air as a reactant for biomass two-stage gasification process, Brandt et al. [44] studied the tar reduction in gasification process for application of synthesis gas in the internal combustion engine. It was presented that the tar content in produced gas reduced less than 15 mg/Nm^3 and none of which was heavy tar. Wang et al. [46] examined the two-stage biomass gasification process with oxygen-enriched air as a reactant. It was revealed that the oxygen concentration had a significant effect on the synthesis composition, but less on the ratio of H_2/CO. The ratio of H_2/CO was around 1 in all experiments, although the concentration of H_2+CO increased from 30 V% to 70 V% at oxygen concentration 21 V% and 99.5 V%, respectively. The O_2-CO_2 was considered as a reactant in the research of biomass two-stage gasification process with the focusing on tar, sulphur compounds, and synthesis gas composition as well [47]. It was demonstrated that the presence of CO_2 led to a reduction in H_2 concentration, but an increasing trend in CO_2 and CO concentration. As O_2-CO_2 operation, the synthesis gas had a high quality with tar and sulphur concentration. It led to higher flexibility in application.

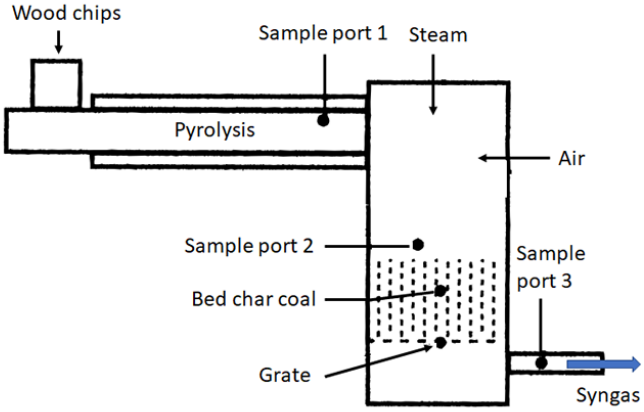


Figure 7
The single-line two-stage gasification process [44]

Brynda et al. researched the biomass gasification unit (named as GP750) to use a combination of physical and non-physical modification for the combined heat and power plant [48]. In this study, there were two air-stages used in a fixed bed gasifier. The first air intake was supplied for the partial combustion stage in the gasifier to produce the essential heat. The char and gas went down to the reduction zone. However, a ceramic cone separator was used between the combustion and reduction stage. This separator only split the gas compounds from the partial combustion zone. The second air intake was provided for partial oxidation of the volatile matter inside the separator. After that, the mixture of gases passed through the hot char bed for further reaction. During the long-term experiment with air as a reactant, the H_2 and CO concentration were remained at around 23 and 25 V%, respectively. Especially, the lowest tar content was 4.1 mg/m^3, normally in a range of 5 to 50 mg/m^3.

CONCLUSION

The above approaches mainly focused on the multi-stage gasification of biomass fuel to enhance the quality of synthesis gas, especially in the reduction of tar content to use in combustion process as internal combustion engine or combined heat and power plant. In addition, using air as reactant showed the poor result in the ratio of H_2/CO for further direct application in the chemical process. There is a gap in the research on single line multi-stage gasifier with the external heat source to examine the effects of operation parameters and reactant on the gasification process of Hungarian brown, as well as optimisation the multi-stage gasification process for fine-tuning the ratio of H_2/CO with the highest conversion efficiency.

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