Переробка сировини та ресурсозбереження

УДК 662.741.3.001.5(047)
DOI: 10.33070/etars.1.2021.03

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Actual Problems of Gasification of Fossil Raw Materials, Biomass and Waste with the Receipt of Fuels and Chemical Products (Analytical review of conference materials "GASIFICATION INDIA 2019", "FROM WASTE TO ENERGY 2019")

The materials and information characterizing the state of the modern world gasification industry of various raw materials and its technologies for obtaining a wide range of energy carriers and chemical products are presented. The main trends and prospects for the further development of gasification and ways to solve the associated problems are reflected. *Bibl. 18, Fig. 3, Tab. 5.*

Keywords: gasification, raw materials, biomass, waste, technology, equipment.

In recent years, India has regularly held annual conferences on gasification. So, from 2010 to 2014, five conferences were held under the heading "Coal – Gas", Coal Asia, from 2015 to 2019 – five conferences under the heading "Gasification India". The most recent Gasification India 2019 conference was held on November 28–29, 2019 in New Delhi, India. It brought together investors, gasification plant owners and operators, synthesis gas consumers including power companies, chemical companies, fertilizer manufacturers, technologists and financial industry experts

to discuss the challenges and prospects facing the growing gasification sector. The conference covered a wide range of technological issues. Topics of the plenary sessions and panel discussions were, in addition, consideration of supply chains, financial support, finished product trading and marketing systems, strategies and opportunities of gasification market, problems and forecasts for the further development of gasification on global and regional scale based on the comprehensive information presented and developments in the field of gasification.

At the same time, “Waist-to-Energy 2019” Conference and Trade Show was held in parallel in the same place. Its goal was to achieve a better understanding of the role of solid and liquid waste as raw materials in the production of energy, fuels, chemical products and to create opportunities for the choice of economically competitive and environmentally friendly technologies for their processing. In practice, participants in these events had the opportunity to attend technical sessions and panel discussions in two areas: Gasification India 2019 and Waste to Energy 2019. They were attended by a wide range of specialists and experts from India and other countries, as well as from the world's leading companies in the field of energy production (including renewable energy), gasification of coal, waste and biomass, and developers of gasification technologies, etc. from research organizations and companies.

Coal gasification

Air Products (AP), USA, presented a report **“Technology of Pulp Gasification by Air Products: Petroleum Coke and Coal”** [1]. The AP technology is based on the use of upflow gasifier with pulp feed and slag formation. Walls of the gasifier are lined with refractory materials. Hot syngas is cooled directly in the gasifier during water spray and, due to its saturation with vapor, is ideal for the CO shift reaction. Pressure in the unit totals 87 bar, and its volume ranges from 900 to 1,800 cubic feet. In addition, AP offers the option of cooling synthesis gas in the radiant cooler with heat recovery before the phase of cooling it with water, with formation of steam at pressure of up to 138 bar.

AP has accumulated some experience in pulp gasification using petroleum coke and coal, starting in the 1960s, through R&D, pilot tests, and then construction of industrial plants. It possesses the plants where 100 % of the captured CO₂ is used to enhance oil recovery (EOR) and eliminate its emissions into the environment. Since 1993, the company has built and commissioned more than 50 plants in China with gasifiers of a 450–900 cubic feet volume. A plant of Coffeyville Resources, USA, which produces nitrogen fertilizers, operates under the license of AP. The TECO Polk Power Plant operates a 1800 cubic feet gasifier producing syngas for power generation using a General Electric gas turbine and supplying 250 MW of electricity to the grid. One of the largest in the world — ZTHC Zhongtian

gasification plant, commissioned in 2016, has 10 working and 4 standby gasifiers with a volume of 900 cubic feet each with pressure of 65 bar, producing 3.6 million tons/year of methanol. AR offers turnkey gasification complexes for production of commercial synthesis gas (SOG), as well as licenses and equipment.

Air Products Syngas Solutions (APSS), USA, made a presentation on **“Dried Coal Gasification Process by Air Products and Improvement of the Lu’An Project”** [2]. APSS has considerable experience in developing and commissioning gasification plants for dry coal injected into gasifier. In 1976, it developed a pilot plant in Amsterdam with capacity of 6 tons of coal per day, and then built a number of plants in South. Korea Vietnam and EU with capacity of 150–3,200 t of coal per day. Most of them were built in China, where APSS sold a license for the plants of > 2,000 t/d. The most high output one is Lu’An gasification plant (3,200 t/d). A total of 32 dry coal gasification plants have been built worldwide under APSS license.

New projects of the company include Talcher plant (in the state of Odisha, India), which produces 2,200 t of ammonia per day and 3,850 t of urea per day. It operates under the of dry coal gasification technology where coal is a mixture of high-ash coal with 40–47 % of ash and 25 % of petroleum coke. Two options are used by APSS in the dry coal gasification technology: 1) a gasifier paired with a synthesis gas cooler; 2) a single unit for gasification with a builtin syngas water cooling system. Each of them has its own advantages. The first one is a field-proven reliable technology with carbon conversion rate of more than 99 %, high energy efficiency, and high steam parameters, and less water consumption and less waste water. The second one provides carbon conversion rate over 99 %, reduced capital costs, more coal flexibility, easier maintenance and repair, and higher reliability.

APSS has been considering availability of a membrane wall with multi-burners in the gasifier to be a distinctive element of its technology, and its advantages include high degree of carbon conversion and low oxygen/coal consumption; high production capacity of the gasifier and easy scaling by means of multi-burners; longer service life of multi-burners; better slag collection; less energy loss.

APSS has tested its technology for processing high-ash coal with ash content at the burner mouth of up to 25–35 % at several sites and has demonstrated:

- the technology is flexible in terms of raw materials, which is confirmed by the experience of processing more than 200 types of coal, including: lignite, sub-bituminous coal, bituminous coal, anthracite, as well as petroleum coke;

- availability of developed models that allow to process new coals and optimize the composition of coal blends;

- high rates of reliability of APSS plants (98.4%), as well as in terms of the duration of continuous operation.

APSS established a joint stock company with Lu'An Clean Energy (60 % of the shares belong to APSS, 40 % – to Lu'An) and built a gasification plant producing 825 thousand cubic meters/hour of synthesis gas ($\text{CO} + \text{H}_2$). The plant was commissioned in August 2018, in 2019 it worked 95 % of the operable time. It has four APSS gasifiers with a 3,200 tons/day capacity of dry coal and four air separation units with capacity of 3,000 tons of oxygen per day. Fig. 1 shows the process flow diagram of the AP – Lu'An gasification plant.

Fig. 1. Process flow diagram of the AP – Lu'An gasification plant.

When operating on anthracite with 20 % ash content, the plant reached 99 % of carbon conversion. Each of the gasifiers has worked 95 % of the operable time in 2019. In a short time, the company managed to achieve high efficiency rates of the plant's reliability.

Antiwear Valves (Suzhou) Co., Ltd (ATW), China, made a report “What is a Wear Resistant Valve and How Does It Serve India Coal Customers” [3]. ATW renders services and supplies valves for chemical, petrochemical, energy and other enterprises and uses services of qualified vendors (Sinopec, Shell – SCGP, U-Gas, CNOOC,

etc.). According to ATW, in China, the most developed is chemical industry, which produces a variety of products from coal: fertilizers, methanol, gasoline, olefins, aromatic, nitrogenous and other compounds. China has almost all gasification technologies available in the world: GE, E-Gas, U-Gas, SCGP, etc., has many manufacturers and suppliers of equipment as well as companies that build gasification plants. Coal gasification plants and chemical production plants use a large number of various valves and gate valves (ball valves, regulating valves, control valves, disc valves, check valves, etc.). They are equipped with oxygen and suspended mixtures supply systems, filtration systems, various bunkers, etc. ATW has supplied a significant number of assorted valve kits for them. ATW works according to international standards and cooperates with a number of well-known world companies. Its products are distinguished by their reliability and long service life. ATW is tooled up with the up-to-date order management systems.

Schmidtsche Schack (ARVOS Group) Company, hereinafter referred to as the Company, presented a report “Advanced gasification technology for a wide range of raw materials and examples of practical solutions” [4]. The Company is registered in India as a legal entity with its office in Mumbai. It is a designer and manufacturer of different gasification processes for coal, biomass and wastes, renders engineering, supply and design implementation services as well as owns a number of subsidiary companies, engineering hubs, production capacities and trade offices in various countries.

The Company has been present in world gasification market since 1967 when it manufactured the cooler for syngas of oil gasification unit. By the moment it significantly extends the scales and fields of its gasification activity. The Company has a perspective evaluation of gasification technology as a comprehensive process aimed for processing of wide range of raw materials:

- Conventional (coal, petroleum coke, residuals of vacuum processing and heavy oils/oil sands, natural and other gases, industrial products);
- Biomass (plants, timber, agricultural wastes, black liquid, etc.);
- Municipal wastes including plastic materials being used for recycle.

Above mentioned raw materials can be in solid, liquid or gaseous state and their processing will require different methods of preparation/prior treatment and supply into process as well special

technologies (gasification, partial oxidation, etc.). Produced syngas will be cooled (by radiant or convective method), quenched, de-ashed, filtrated, dried and segregated (with basic separation of H_2 , CO , CO_2 , admixtures). Gasification processes have different parameters and features and go under conditions inherited to them only.

The Company is ready to solve the tasks and problems connected with practical implementation of gasification technologies including the mentioned special features inherited and has the required solutions and multi-year experience. First of all it refers to the technical concepts of equipment design and known common technologies of gasification (in fixed bed, in fluidized bed – CFG and BFB, double fluidized bed, in upstream). The Company has the following technologies of syngas cooling (quenching with cold gas, chemical and water quenching, convective and radiant one).

Key fields of the Company competent activity are:

- cooperation with Shell and Air Products Companies in coal gasification technologies (SCGP), oil and gas based gasification technologies (SGP) and their distribution;
- supply of significant part of details and units for solid municipal wastes gasification technology in the USA: steam drum, gasifier, radiant and convective coolers for syngas (Fig. 2);
- manufacturing of convective heat exchanger system for CORTUS WOODROLL® process of Cortus Energy Huganas unit (biomass gasification with generation of 6 MW electric power);
- manufacturing of the most critical equipment for the plant of timber production wastes treatment (black liquid) – gas generator, syngas cooler with steam generation, absorber, oven for limestone burning.

Fig. 2. Supplies of the Company for municipal solid wastes gasification (MSW) in the USA.

The Company manufacturing capacities are described by the following main figures: the amount of time accumulated by production during a year – 230 thous. hours, occupied areas – 22390 m^2 , max lifting capacity of cranes – 160 t, 100 % supervision by its own personnel.

Indian company DEV Energy presented a report “Innovation solutions in coal gasification: our experience” [5]. DEV Energy (hereinafter referred to as DE) with 15-year operation experience is specialized in supplies of coal gasification systems for gaseous fuel/heat production for different industry sectors: production of glass, ceramics, tiles for walls and floors, gratings for heating and firing kilns, power blocks for metallurgical industry, etc. The main type of gas generator manufactured by this company is double-staged with fixed bed.

The highest capacity of DE gasification system – 100 thous. nm^3 /hour of gas. There are some facilities for which DE provided the plants with the capacity of 8, 9, 15, 18, 80 thous. nm^3 /hour of gas. Gas generating systems distributed by the company ensure the following: processing of fine coal with low temperature of ash melting using oxygen; production of about 40 thous. nm^3 /hour of gas by one system; no need for tar treatment and phenolic waters production; high degree of hydrogen conversion – 90–95 %; simplicity of start-up and stopping.

The Company intends to use such systems further on and to enhance them in order to utilize the ranked coal; hard coal with high temperature of ash melting; achieve the production capacity of about 100 thous. nm^3 /hour of gas by one system; use the low carbon raw material for conversion; use the lean gas (mixture of nitrogen gas and air) as a carrier.

ESVIN ADVANCED TECHNOLOGIES Ltd. (hereinafter referred to as ESVIN) registered in India made a report on “Lignite gasification with high quality syngas generation for fuels and chemical products production” [6].

Some time ago ESVIN bought the exclusive license for indirect gasification from USA Company MTA (Baltimore), gained the experience in gasification of black liquid and industrial waters of distillation processes and today promotes in market the gasification of raw materials from lignite to biomass together with its USA partner Thermechem Recovery International (TRI Inc.). In its technology the raw material is processed by steam reforming in fluidized bed. Besides ESVIN cooperates

Table 1. Lignite reserves in India (mln t)

State	Proven	Unproven	Total
Tamil Nadu	2831	28091	30922
Rajasthan	561	3675	4236
Gujarat	785	1878	2663
Total	4177	33644	37821

Table 2. Potential of fuels gasification

Raw materials for gasification	Fixed carbon, %	Volatile
Anthracite	95	5
Bituminous coal with low content of volatile matters	80	20
Bituminous coal with average content of volatile matters	72	28
Bituminous coal with high content of volatile matters	56	44
Sub-bituminous coal	50	50
Lignite	40	60

Table 3. Approximate analysis of different coals

Index	Lignite	Indian sub-bituminous	SAR coal	Indonesian coal
Moisture content, %	50.0	10.0	8.50	31.0
Ash content, %	6.0	34.65	17.00	4.0
Content of volatile matters, %	29.0	20.70	23.28	34.0
Fixed carbon, %	18.0	34.69	51.22	32.0
Volatile (volatile + swelling index), %	62.0	38.0	32.0	52.0
Highest heat of combustion, kcal/kg	2700	4500	6000	4600

Table 4. Characteristics of lignites from other regions of India

Index	Gujarat	Rajasthan	Neyveli
Moisture content	37	40–49	48–52
Ash content, %	10	17–24	4–8
Content of volatile matters, %	27.5	20–26	25–29
Fixed carbon, %	25.5	12–20	18.5–19.5
Volatile (volatile + swelling index), %	52.0	59.0	58.7
Highest heat of combustion, kcal/kg	3600	2000–3000	2500–2900
Sulphur content, %	4.0		0.8–1.3

with Swedish company Exergy AB, Gothenburg as to the using the technology of biomass, lignite, coal, etc. drying with superheated steam.

Below you can find some data which ESVIN believes will prove the expediency of gasification technology promotion in India (Tables 1–4).

ESVIN reckons the lignite drying technologies mastered in the industry production as follows:

- Drying in “fluidized bed” by means of steam heater, used at Niederaussem HPP, RWE Power (Germany);

- Technology of Swedish company Exergy (Swedish Exergy Steam drying process).

It was noted that China, for example, has a wide range of direct (proper) coal gasification technologies supplied by foreign vendors (GE Energy, Shell, Siemens, SES) and that TRI Inc. along with them, he is the owner of the indirect gasification technology mastered in industry production, which is characterized by the following features:

- “deep fluidized” bed;
- it uses the process of raw material reforming by means of average temperature steam with low pressure;

- System has three inlets (for lignite, fuel gas for impulse heating and steam for fluidized bed) and three outlets (for syngas rich with hydrogen, pure fuel gas and solid wastes of fluidized bed). Tail gas of syngas conversion processes is usually used as a fuel gas;

- lignite is dried with reduction of volatile matters and steam reformed.

TRI Inc. is the owner of impulse heater design, which used in the mentioned technology and which ensures the highly efficient transfer of heat and cost-effective design of “fluidized” bed detail.

TRI Inc. system of syngas production is double staged. It provides the flexibility with wide range of raw materials, and has a unit of “deep fluidized” bed at the first stage, where the raw material is dried and subjected to pyrolysis and steam reformed. Steam reformer has a height ~18 m, weight – 110 t. Indirect gasification ESVIN with steam reformer ensures the following content in syngas: 48.5 % H₂, 21.8 % CO and 25.2 % CO₂.

Commercial example of above mentioned technology is the plant being built in Nevada state with processing of 500 t/day (d.s.) of municipal solid wastes and production of 10mln gal of fuel for jet planes (is supposed to be commissioned in January, 2020).

International company FLUOR made a presentation “**The use of low-quality coals for methanol production. Specific example**” [7]. FLUOR corporation is widely known in the world market for providing services in the field of gasification of various raw materials (coal, petroleum coke, solid waste, other waste and residues) with obtaining a wide range of products (methanol, synthesis gas, electricity, ethanol, liquid products, etc.). During the period since 1980, it performed a number of works in many countries (USA, Indonesia, India, France, Italy, etc.). In most cases, the company distributed well-known gasification technologies (GE, Shell, Siemens, ECUST, Lurgi, etc.), including those based on the main primary gasification reactions:

- partial oxidation ($2\text{C} + \text{O}_2 \rightarrow 2\text{CO}$);
- steam gasification (reforming)
($\text{C} + \text{H}_2\text{O} \rightarrow \text{CO} + \text{H}_2$);
- steam-gas shift reaction
($\text{CO} + \text{H}_2\text{O} \rightarrow \text{CO}_2 + \text{H}_2$);
- methanation ($3\text{H}_2 + \text{CO} \rightarrow \text{CH}_4 + \text{H}_2\text{O}$).

These processes take place at temperatures of 900–2000 °C and a pressure of 0.3–8.5 bar and are also characterized by the following points:

- water steam-gas shift reaction is used to regulate ratio H_2/CO as required by the final product;
- synthesis gas is treated with removal of acid gas from it so that further synthesis gas catalyze can be possible as well as the environmental protection standards can be complied;
- sulfur is captured as fused sulfur or sulfuric acid;
- there are possibilities for capture of CO_2 and its transfer to coal seams either for enhanced oil recovery (EOR) or storage.

FLUOR notes that gasification is a complex and combined process with many challenges that require:

- integration of technologies of several areas during project implementation;
- attention to process tooling, corrosion, catalyst life and control;
- special attention to capital and operating costs from the very beginning;
- participation of a highly qualified team with experience in the field of gasification;
- frequent routine repair and restoration work with the replacement of specific components, which necessitates shutdowns.

As an example of one of these processes, they give a specific example of obtaining from coal the methanol, which has a wide range of uses (traditionally – for the production of formaldehyde,

acetic acid, methyl methacrylate, etc.; new directions – for the production of olefins, gasoline mixtures, dimethyl ether, biodiesel, etc.). Methanol is a clean fuel product that, when burned, does not generate suspended solids, soot, emissions of SO_x and NO_x . Its utilization has become widespread in the world market.

The global methanol production capacity is 120 million tons/year and by 2025 will be 200 million tons/year. China alone produces 65 % of the world's methanol and uses its coal for this.

Israel and Italy have adopted the M15 programs – mixing 15 % methanol into fuel for cars and are rapidly approaching the adoption of the M85 and M100 programs Japan and South Korea widely uses methanol and dimethyl ether, while Australia switched to GEM fuels (gasoline, ethanol and methanol) and blends containing almost 56 % of methanol.

In India there are capacities for the production of 2 million tons/year of methanol from natural gas. According to the NITI AAYOG plan, by 2030, 30 million tons of methanol will be required to replace imports of 10 % of raw materials. Currently, the government has set a target to reduce imports by 10 % by 2022. This target can be achieved by gasification of its own low-quality coals with a high ash content, the reserves of which India ranks 5th in the world.

As an example, data on the creation of a capacity for the production of 2250 thousand tons / year of methanol from coal with an ash content of 35–40 % by weight are given. with a price of 20–40 US dollars for 1 metric tonne: consumed water costs 0.06 US dollars per ton; produced sulfuric acid – 78 USD/t, the price of operating costs and repairs is 2–3 % of capex. Some economic indicators for this example are shown in Table 5.

Table 5. Economic indicators for the specific case

Price of coal, USD/metric tonne	Cash price of methanol, USD/metric tonne	Cash price of methanol, INR/metric tonne
20	180	10.2
30	200	11.4
40	220	12.5

It was noted that the price of methanol imported to India is 290–320 US dollars/mt.

It is concluded that gasification is an effective way of converting low-quality coal into a product with high added value. It will reduce India's need

for imported fuel and boost methanol production. Several operating facilities have already shown good results. It is necessary to use the best technologies and use the services of qualified engineering development companies with experience in the field of gasification.

Indian company JSPL made a report “**Coal gasification. Possibilities and issues for Indian companies**” [8]. Steel plant of JSPL company in Angul is the only Indian facility with a coal gasification unit and the world's first DRI unit fueled by synthesis gas. According to JSPL, the global coal gasification market is characterized by the following data. There are 272 coal gasification plants worldwide with 686 gas generators, 74 units with 238 gas generators are under construction. For 2018, the total capacity of coal gasification units for syngas was 250 thousand MW/h. Their number is growing in China, Mongolia, South Korea, India. The products of these plants are ammonia (25 % of world production) and methanol (30 % of world production). Growth in consumption of produced synthesis gas in 2018–2019 made up 310 thousand MW/h, including 140 thousand (45 %) – in chemical production; 55 thousand (18 %) – in liquid fuels production; 25 thousand (8 %) – in electric power production; 90 thousand (29 %) – in gaseous fuels production.

China is leading in the scale of coal gasification and its processing into liquid products. In this country, the chain “coal gasification + coal – into liquid products” provides 80 % ammonia/urea and 90 % methanol production. The production of automobile fuel, in which methanol is mixed, is growing, as well as products along the chain “coal – into liquid products”.

India has huge reserves of coal, but their production is low, so the country imports annually chemical and petrochemical products worth 45 billion US dollars. At the same time, 50 % of these goods can be produced in the country by gasifying coal and processing it into liquid products, and save 21 billion US dollars/year. Several potential coal/petroleum coke gasification projects are currently being considered. In this direction, India has a huge potential, but there are a number of serious problems, for example, the low quality of non-coking coals, a large amount of accumulated small coals in warehouses and problems of their utilization, a long distance of transportation, the lack of mines for the extraction of coal for gasification, etc.

India's gasification technology faces great challenges in terms of environmental protection

(the large amount of wastewater generated and the high cost of treatment, capital-intensive systems of recovery of CO₂, H₂S and dust, issues of utilization of CO₂, and etc.). One of the serious problems is the choice of technology for gasification of low-quality Indian coals and the development of projects (this concerns the issues of coal preparation, uncertainties with frequent changes in the owners of gasification technologies in the world market, high capital costs and a number of commercial and financial problems that are critical for a country like India). The key priority tasks are the creation of national programs in the country, the construction of coal mines, the adoption of financial measures by the government, the introduction of schemes for the production of mixtures of methanol, dimethyl ether with gasoline, etc.

Company Oke (Oranje Kracht Engineering), India, focused its report on the subject “**Missionary energy and gasification technology inspirers**” [9] on the opportunities for India with the widespread adoption of gasification technologies. In the first place are the tasks of obtaining renewable energy, diversifying agriculture and creating alternative fuels. The creation of the Indian Gasification Council is urgent.

TRUE NORTH Venture Partners (TN) company, USA, devoted its presentation to the subject “Coal Into Chemical Products: Opportunities and Barriers to Indian Energy” [10].

Being a joint stock company with seven shareholders, the company has a large field of activity in the field of investment in innovative technologies and business, in modernization of industries, etc. TN turns its focus in participation in the Indian market with the production of synthesis gas using various feedstocks, electrolysis hydrogen, ceramic membranes for water filtration, conversion of methane to chemical products, waste processing, etc. TN has especially great prospects in production of chemical and petrochemical products, where demand is predicted to grow by 12–14 % and its imports have reached 130 billion US dollars. India is expected to surpass China in primary energy consumption over the next three decades. India has the necessary natural resources for the production of various types of energy (solar, biomass and coal, etc.). However, given coal's poor reputation as a pollutant, TN has no plans to build new coal-fired power plants. Alternative, clean coal conversion technologies that are widely used in world practice, in particular, based on the production of synthesis gas will be prioritized.

The total geological reserves of coal in India are 319.02 billion tons, 47 % of them are explored. Indian coal mainly belongs to the categories of bituminous and sub-bituminous, most of which is non-coking. Most Indian coals have a high ash content, in this regard, the choice of technology for their gasification becomes especially important and it is necessary to choose proven technologies intended for gasification of coal.

It is noted that the economics of coal gasification and the cost of synthesis gas largely depend on the final purpose of using syngas, which determines the requirements for it (gas composition and H_2/CO ratio, its pressure, impurities content, preliminary processing of raw materials and its characteristics and others), and most of these factors do not depend on the price of coal. Operating and technological conditions, amount of capital costs, location of the plant, availability of raw materials, etc. also have a considerable impact on the economics of syngas production process, and yet the cost of syngas production is considered to be 32–35 % lower than for the conventional chain “coal into ammonia”. TN believes that the technology of converting Indian coal into chemical products has all the necessary advantages and should be developed.

Waste and biomass gasification

American company Beltran Technologies, Inc. reported of “Waste conversion to generate renewable energy” [11]. The company believes that the main focus in this direction is to create decentralized, efficient and small-scale biomass/waste gasification plants using combined gas-fired generators to produce electric power and heat. All kinds of waste (garbage) contain ~ 70 % biomass and are a reliable source of renewable energy. This conversion can be implemented by the following processes:

- thermal processes (combustion, gasification, pyrolysis);
- biologically with biogas production;
- hydrolysis at high pressure and temperature to obtain liquids.

As an example, a diagram of a biomass gasification unit with an internal combustion gas turbine is shown (Fig. 3).

Beltran possesses a patented proprietary gas generator design that combines drying, pyrolysis, oxidation and reduction zones. The raw materials gasified by the company include:

Fig. 3. Diagram of a biomass gasification unit with an internal combustion gas turbine.

– waste wood, solid waste, sewage deposits, industrial waste, waste from poultry farms, leather production, etc.;

– biomass: sugar cane waste, straw, palm oil waste, coconut shells, cotton bolls, etc.

Waste gasification process, for example, is characterized by the following indices:

- 2.2–2.5 nm^3 of gas is produced of 1 kg of waste (with a moisture content of 20 %);
- density of the cooled and cleaned gas is 1.027 kg/nm^3 ;
- energy capacity of gas 5–6 MJ/nm^3 ;
- waste/biomass consumption is ~ 1 kg per 0.8–1.2 kWh of electricity.

Indian company Punjab Renewable Energy Systems Pvt. Ltd. (PRES) made a detailed report to the subject: “Valuable sustainable biomass-to-bioenergy process chain: aggregation, processing and delivery to ensure the reliability of biomass-based projects” [12]. PRES specializes in collection of various types of biomass/agricultural waste, their storage, preparation and transfer for utilization to biomass power units or to processing plants. It has created a large-scale chain covering all stages of the process — from field to factory, as well as a system for providing services to farmers in collecting biomass on a long-term basis. The company has its own plants to process the biomass for transportation (for example, in form of briquettes, etc.). Moreover, PRES provides consulting services for biomass assessment, preparation of feasibility studies for creation of biomass power units and their management, etc. The scope of the company’s activity at all the listed stages covers: development of business plans; preparation of data on the cost of biomass and equipment (an example of a specific processing plant with an annual capacity of 110 thousand tons is given); determina-

tion of the influence of socio-economic factors on development of territories covered by the company's activities, etc.

Indian company Boson Energy. The Imby Company made a report on the subject: **"First mile. Turning waste from a real threat into a resource that sustains our existence"** [13]. Noting the vitality of solving the issue of waste disposal on a global scale, the company believes that this task can be solved by creating local small-scale installations that will provide additional value at the place of generation and subsequent processing of waste (solid, medical, hazardous waste, etc.). In its opinion, large-scale incinerators have proven their inability to combine waste storage with land reclamation. This is why Boson is focusing on the creation of 100–300 TPD waste handling plants using its innovative integrated plasma gasification technology (Boson's PAG).

As reported by the company, such plants are highly efficient and provide low capital and operating costs, and their emissions are below the EU limits (for particulate matter – 40 %, HCl – 25 %, SO₂ – 15 %, NO_x – 39 %, Hg – 40 %, Cd + TI – 40 %). Boson's technology enables waste gasification to produce syngas that can be used for energy, heat generation and for cooling. Boson gives a number of feasibility studies to support the benefits of its technology:

- Comparison of capex consumption per ton of annual capacity of various projects and the impact of incineration costs with ash production on EBITDA (which determines the amount of profit before deductions). For Boson's technology, the capex for a processing unit of 100 thousand tons of waste per year makes up < 50 million euros, besides the lower operating costs and emissions;

- UN data for 2015 on the value of costs for various waste treatment processes, including for developed and developing countries;

- Conclusions that Boson's technology matches the cost structure of developing countries;

- Numerical data on economic benefits of introducing Boson's technology in comparison with the costs of landfilling and soil reclamation, as well as for large-scale incineration;

- Thesis that Boson's technology has advantages over small and medium scale combustion technology in terms of its capex and key indicators.

The Center for Energy Problems of the Indian Institute of Technology made a detailed presentation on the subject **"The new role of bioenergy in creation a bioeconomy that meets energy security"** [14]. It covers the following main issues:

- Energy scenario in the world and India;
- The need for biofuels in comparison with other types of renewable energy and conventional ones;
- Engineering and management of biomass processing;
- Biofuel options;
- Biomass conversion technologies;
- Future expectations.

At present, the share of consumption of various types of energy sources in the world is: oil – 33 %; coal – 30 %; natural gas – 24 %; hydropower – 7 %; nuclear energy – 4 %; renewable energy – 2 %.

During the last decade, the consumption of various types of energy in the world amounted to: fossil fuels about 80.1 %; renewable energy – 16.7 %; nuclear energy – 2.7 % of the total. In 2016, the global production of biofuel amounted to 82 million tons, its share in transport fuel is 4 %. The world's biomass resources can cater 66 % of energy demand. There is an increase in plants of biomass processing to produce energy. India produces 500 million tons of biomass annually. The Center believes that this offers challenges for the country and argues for the need for biomass processing. The world production of biofuels is growing. In 2016, the USA produced 82 million tons, followed by Brazil, Germany, Indonesia, Argentina.

Three directions of biomass conversion are possible: chemical, thermochemical and biochemical. Biomass conversion technologies are characterized by both their diversity and the breadth of raw materials and products range. The resource and commercial components of biomass conversion process flow diagrams require some analysis. The report provides brief characteristics of lignocellulosic biomasses and chemical products made of hemicellulose and lignin, as well as brief calculations on oilseeds, various oils, algae to biodiesel production. The USA is the largest producer of biodiesel (6.9 billion gallons), followed by Brazil, Indonesia, Germany, Argentina, France ... India.

The report discusses the issue of liquefaction of biomass to produce liquid fuels (CO + H₂O, H₂-catalyst, pressure 100 atm, temperature 300–400 °C). In order to improve the quality characteristics of biofuel and its yield, catalytic cracking is used. If gasification of biomass is carried out under pressure, then methane is produced along with other gases, where Na₂CO₃/K₂CO₃ is used as catalysts. Syngas can be used in Fischer-Tropsch synthesis.

For the production of petroleum hydrocarbons, oxo-synthesis can alternatively be used to produce

alcohols. Since biomass contains more than 20 % moisture, there is no need to add extra steam into gasification process. Gas generators designed for coal can be used to gasify the biomass, and liquid fuels can be produced of gaseous fuels. Below equations can be used as an example:

$\text{CO} + \text{H}_2 \xrightarrow{\text{oxo-synthesis, Fischer-Tropsch synthesis}} \text{CH}_3\text{OH}$
or carbons;

$\text{CH}_3\text{OH} + \text{oil} \rightarrow \text{gasohol}$ (a mixture of gasoline and ethyl alcohol).

The report focuses on the use of algae — the third generation of biomass. As reported by DOE (USA), algae have an energy potential of 30 times more than agricultural waste used to produce bio-fuels. Algae have 2 % of the total share of carbon, however, they absorb up to 50 % of atmospheric CO_2 (30–50 billion tons/year), converting it into organic carbon. They provide nearly 50 % O_2 production through photosynthesis. In world practice, there are the following examples of the use of bio-fuels: Brazil — 27 % of bioethanol is mixed into motor fuel, 7–10 % of biodiesel; China — 10 % is mixed; EU — 20 %; India — up to 20 %. The Committee on Biomass Research and Technology Development (USA) has set a target to supply 20 % of biofuels, 25 % of chemical products and 5 % of electricity based on biofuels by 2030.

The Center believes that there is a need to organize bioeconomics and total replacement of fossil fuels with biological ones. It is concluded that global warming requires a bias towards bioenergy and hydrogen production in conjunction with the creation of energy based on fuel cells. USA, EU and other countries, including China, are making progress in implementing programs for the production of bioethanol, biodiesel, biogas, i.e. are already organizing the bioeconomy. India also needs to intensify work in this direction.

Indian company Innovative Eco-Care Pvt Ltd. (IEC) reported to the subject **“Recycling of solid municipal waste to produce energy without soil reclamation”** [15]. IEC considers that MSW gasification is the most suitable way for India to recycle it, combined with IEC proprietary solid waste management technology, i.e. their controlled decomposition to extract resources. Controlled decomposition takes place using a mixed microbial culture (inoculum) Renerzyme, recognized by the WHO as a safe microbe. The decomposed waste is sent for sorting to extract (produce) such resources as: compost; waste fuel (RDF — refused derived fuel) used for further processing of reagents, paper,

metals, etc. Waste used for energy production (RDF) is gasified, burned in boiler plants, etc. The process is clean and harmless. It allows to recycle municipal various composition solid wastes, reduce energy consumption for drying. The comparison of indicators of waste incineration processes and IEC technology (microbiology + gasification) is reported. The presentation contains many photos of the IEC process line at Imphal, Manipur.

Ecomakluehr company (India) delivered a presentation to the subject **“The ultimate fuel gas treatment system for waste-to-energy plants”** [16]. The company is a joint stock company with constituent companies ECOMAR, a supplier of fuel gas treatment units (26 years in the Indian market) and LUEHR FILTER, a global company with over 80 years experience in the fuel gas treatment plants. Both companies have extensive references in using fabric filters for various processes, supplies and services (separators, dust injection, electrostatic precipitators, absorbers, etc.) in the fields of foundry, ferrous and non-ferrous metallurgy, cement and chemical industry, etc., as well as in the field of incineration of solid waste, industrial waste, biomass, sludge (sediments), rubber products, etc. The Ecomakluehr's technology provides for raw fuel gas purification by dry sorption including conditioning in a rotary reactor, chemisorption (with particle conditioning) to remove dust, SO_2 , NO_x , NH_3 , mercury, CO, etc. up to BAT values.

Other technologies

Indian Company Avant — Garde made a report on “Combustion technology of mass” [17]. The Company promotes the technological processes connected with combustion mainly municipal solid wastes at high temperature and oxygen availability. The wastes are divided as “received” and preliminary treated. The first are not preliminary treated and their combustion is called “Direct combustion of mass”. The second requires the implementation of different preparation processes. Combustion generates the heat energy. Combustion technologies used for the same are called “Wastes — to heat”. They are divided into three types: on moving grate; in “fluidized” bed; in rotating ovens. The company activity covers more than 40 countries.

Reliance Industrial Limited (RIL) Company, India made a presentation of “Catalytic hydrothermal fluidization RCAT-HTL” [18]. RIL is known as the most profitable Indian company in

Indian market. It is the leading company in the field of energy and raw materials for its generation (petrochemical industry and deep seabed mining, etc.). The Company conducts scientific and research activities, has inventions and patents, for example in the field of algae processing. One the Company new subjects is the technology of catalytic hydrothermal fluidization RCAT-HTL (algae – to oils). It covers the algae growing, harvesting, processing into biomasses. The Company considers this technology as innovative, ecology friendly and applicable for biomass/wastes processing into renewable energy and bio-products. More than 125 types of catalysts were studied during the technology development. The Company has advantages comparing to others (combustion, anaerobic boiling, hydro-pyrolysis) approving its high efficiency. Plan for development of commercial plant with RCAT-HTL technology is already here.

Conclusion

Conferences and other events of this kind, regularly held by the world community for many years, testify to the fact that the world market for gasification technologies for a wide range of raw materials has developed and is successfully functioning, and gasification technology itself has become an integral part of the world energy sector. Gasification has enormous potential for the development of energetics, chemical industry, metallurgy and other sectors of economic activity, as well as for reducing the release of harmful substances into the environment, especially greenhouse gases. Gasification has long become an effective way of processing coals (including low-quality ones) into products with high added value, which has allowed a number of countries to reduce imports of gas, oil, petroleum products, fuel for vehicles and reduce their energy dependence. Capacities for the production of synthesis gas and products obtained from it are increasing in the world. Modern gasification plants are very flexible in terms of the processed raw materials, the range of which is constantly expanding. The capacity of the installations has significantly increased, the design of gas generators is being improved, and the manufacture of complex equipment for gasification has been adjusted. The creation of small-scale installations for gasification of waste, biomass and other types of raw materials, an increase in the production of biofuel is gaining popularity. The presence of huge world reserves of biomass and the need to create a bioeconomy are noted.

At the conference “Gasification India 2019”, some interesting information was presented on a number of issues and problems, as well as proposals were made that can be applied to the situation in Ukraine with the extraction and use of coal, the provision of energy resources and the processing of waste, garbage, etc. Unfortunately, in Ukraine, with its serious energy dependence, and on the other hand, with large resources of unused raw materials suitable for gasification, no measures are taken or planned at the state level to use gasification technologies in domestic practice. At the same time, the country has scientific potential and serious scientific and technical developments, carried out mainly on an initiative basis, supported by the National Academy of Sciences of Ukraine, the Chamber of Commerce of Ukraine and a number of regional state organizations, which, with appropriate support, allow solving this serious task of a national scale.

References

1. H. Mohammad. Air Products Slurry Gasification Technology: Petcoke & Coal. *Conf. Pros. “Gasification India 2019. Waste-to-Energy 2019”*. 28–29 Nov., 2019. New Delhi, India. — https://missionenergy.org/gasification2019/presentations/Air%20Products_Hidayat-hullah%20Mohammad.pdf/
2. P. Zhe. Air Products dry-feed coal gasification process and Lu'An project update. *Conf. Pros. “Gasification India 2019. Waste-to-Energy 2019”*. 28–29 Nov., 2019. New Delhi, India. — https://missionenergy.org/gasification2019/presentations/Air%20Products_Peng%20Zhe.pdf/
3. S. Deng. What and How Antiwear Valve Serves for Coal Chemical Clients in India. *Conf. Pros. “Gasification India 2019. Waste-to-Energy 2019”*. 28–29 Nov., 2019. New Delhi, India. — <https://missionenergy.org/gasification2019/presentations/Antiwear%20Valves.pdf/>
4. N. Garrels, K. Girotral. Advanced Gasification Technologies Applied To a Broad Range of Feedstocks. Solutions Experience References. *Confrence proseedng “Gasification India 2019. Waste-to-Energy 2019”*. 28–29 Nov., 2019. New Delhi, India. — <https://missionenergy.org/gasification2019/presentations/Arvos.pdf/>
5. V. Kumar. Innovative Solutions in Coal Gasification: Our experience. *Confrence proseedng “Gasification India 2019. Waste-to-Energy 2019”*. 28–29 Nov., 2019. New Delhi, India. — https://missionenergy.org/gasification2019/presentations/Dev%20Energy_Varun%20Kumar.pdf/
6. T.S. Ventkataraman. Lignite gasification to advanced syngas for production of fuels and chemicals. *Conf. Pros. “Gasification India 2019. Waste-to-Energy*

2019". 28–29 Nov., 2019. New Delhi, India. — https://missionenergy.org/gasification2019/presentations/Esvin%20Advanced%20Tech%20Ltd_T%20S%20Venkataraman.pdf/

7. N. Bhongale, K. Singh, S. Singhal. Utilizing low grade coal to produce methanol: a case study. *Conf. Pros. "Gasification India 2019. Waste-to-Energy 2019"*. 28–29 Nov., 2019. New Delhi, India. — <https://missionenergy.org/gasification2019/presentations/Flour.pdf/>

8. D. Sengupta. Coal Gasification. Opportunities and challenges for Indian companies. *Conf. Pros. "Gasification India 2019. Waste-to-Energy 2019"*. 28–29 Nov., 2019. New Delhi, India. — <https://missionenergy.org/gasification2019/presentations/JSPL.pdf/>

9. K. Girotra. Mission Energy — Gasification Torchbearers. *Conf. Pros. "Gasification India 2019. Waste-to-Energy 2019"*. 28–29 Nov., 2019. New Delhi, India. — <https://missionenergy.org/gasification2019/presentations/Kapil%20Girotra.pdf/>

10. D. Gavashar. Coals to Chemicals: Opportunities and Obstacles toward India's Energy Vision. *Conf. Pros. "Gasification India 2019. Waste-to-Energy 2019"*. 28–29 Nov., 2019. New Delhi, India. — <https://missionenergy.org/gasification2019/presentations/True%20North%20Venture%20Partners.pdf/>

11. S. Mitra. Gasification of waste for renewable energy generation. *Conf. Pros. "Gasification India 2019. Waste-to-Energy 2019"*. 28–29 Nov., 2019. New Delhi, India. — <https://missionenergy.org/gasification2019/presentations/BELTRAN.pdf/>

12. M. Ahuja. Bioenergy — Sustainable Biomass Value Chain: Aggregation, Processing & Supply for Sustainability of Bio-Refinery & Biomass Based Projects. *Conf. Pros. "Gasification India 2019. Waste-to-Energy 2019"*. 28–29 Nov., 2019. New Delhi, India. —

https://missionenergy.org/gasification2019/presentations/Col%20Monish%20Ahuja_PRESPL.pdf/

13. Sharma. First-Mile: Transforming waste from existential threat to a resource supporting our existence. *Conf. Pros. "Gasification India 2019. Waste-to-Energy 2019"*. 28–29 Nov., 2019. New Delhi, India. — <https://missionenergy.org/gasification2019/presentations/BOSON.pdf/>

14. D. K. Sharma. Emerging Role of Bioenergy for Establishing Bioeconomy for Meeting the Energy Security. *Conf. Pros. "Gasification India 2019. Waste-to-Energy 2019"*. 28–29 Nov., 2019. New Delhi, India. — <https://missionenergy.org/gasification2019/presentations/D.K.Sharma.pdf/>

15. IEC. Mixed MSW-to-Energy with Zero % Landfill. *Conf. Pros. "Gasification India 2019. Waste-to-Energy 2019"*. 28–29 Nov., 2019. New Delhi, India. — <https://missionenergy.org/gasification2019/presentations/INNOVATIVE%20ECO-CARE.pdf/>

16. Ecomakluehr. State of the Art FGT for waste to energy plants. *Conf. Pros. "Gasification India 2019. Waste-to-Energy 2019"*. 28–29 Nov., 2019. New Delhi, India. — <https://missionenergy.org/gasification2019/presentations/Ecomak.pdf/>

17. Avant-Garde Mass Incineration Technology. *Conf. Pros. "Gasification India 2019. Waste-to-Energy 2019"*. 28–29 Nov., 2019. New Delhi, India. — <https://missionenergy.org/gasification2019/presentations/Avant-Garde.pdf/>

18. R. N. Chandrashekar. Reliance Catalytic Hydrothermal Liquefactions. *Conf. Pros. "Gasification India 2019. Waste-to-Energy 2019"*. 28–29 Nov., 2019. New Delhi, India. — <https://missionenergy.org/gasification2019/presentations/RIL.pdf/>

Received November 26, 2020

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Актуальні проблеми газифікації викопної сировини, біомас та відходів з одержанням палив та хімічної продукції (Аналітичний огляд матеріалів конференцій «ГАЗИФІКАЦІЯ ІНДІЯ 2019», «ВІД ВІДХОДІВ ДО ЕНЕРГІЇ 2019»)

Наведено матеріали й інформацію, що характеризують стан сучасної світової промисловості газифікації різноманітних сировинних матеріалів та технологій одержання різноманітних асортиментів енергоносіїв та хімічної продукції. Відображено основні тенденції й перспективи подальшого розвитку газифікації та шляхи вирішення пов'язаних із цим проблем. *Бібл. 18, рис. 3, табл. 5.*

Ключові слова: газифікація, сировинні матеріали, відходи, біомаса, технологія, устаткування.

Надійшла до редакції 26.11.20

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Актуальные проблемы газификации ископаемого сырья, биомасс и отходов с получением топлив и химической продукции (Аналитический обзор материалов конференций «ГАЗИФИКАЦИЯ ИНДИЯ 2019», «ОТ ОТХОДОВ К ЭНЕРГИИ 2019»)

Представлены материалы и информация, характеризующие состояние современной мировой промышленности газификации разнообразных сырьевых материалов и технологий получения широкого ассортимента энергоносителей и химической продукции. Отражены основные тенденции и перспективы дальнейшего развития газификации и пути решения связанных с этим проблем. *Библ. 18, рис. 3, табл. 5.*

Ключевые слова: газификация, сырьевые материалы, биомасса, отходы, технология, оборудование.