УДК 662.758.2

Synthetic fuel - the fuel of the future

© Svetlana V. Latysheva, Roman S. Maslennikov, Danil M. Volygin, Denis A. Studennikov
Irkutsk National Research Technical University, Irkutsk, Russian Federation

Abstract. For the last decade, experts have been intensively discussing the increasing level of CO_2 in the atmosphere. Most countries are trying to replace fossil fuel energy sources with eco-friendly alternatives. Considering the transport complex, it is evident that the majority of car producers are turning to electric car production. However, e-cars have some disadvantages like discharging, utilisation of the li-ion batteries and quite long charging time. Thus, the internal combustion engine needs reinventing with respect to eco-fuel because humanity has a ready-made infrastructure. There are several ways to produce synthetic fuel, and one of them is the subject matter of this paper. Replacing traditional oil for the production of motor fuels with technology based on the Fischer-Tropsch process can significantly reduce harmful emissions into the environment due to the absence of harmful and toxic impurities, in particular, sulphur and its compounds. SLFs (synthetic liquid fuels) have low concentrations of aromatic substances and a lower formation of benzene, and a lower formation of greenhouse gases.

Keywords*:* synthetic liquid fuel, Fischer-Tropsch process, eco-fuel

Синтетическое топливо – топливо будущего

© С. В. Латышева, Р. С. Масленников, Д. М. Волыгин, Д. А. Студенников
Иркутский национальный исследовательский технический университет, г. Иркутск, Российская Федерация

Аннотация. Последнее десятилетие специалисты интенсивно обсуждают повышение уровня содержания CO_2 в атмосфере. Большинство стран пытаются заменить источники энергии из ископаемого топлива экологически чистыми альтернативами. Если рассматривать транспортный комплекс, то можно заметить, что большинство автопроизводителей переходят на производство электромобилей. Помимо саморазряда и долгого времени зарядки, к проблемам электромобилей относят сложность утилизации и переработки литий-ионных аккумуляторов. Таким образом, двигатель внутреннего сгорания нуждается в переосмыслении в сторону экологичного топлива, так как у человечества есть готовая инфраструктура. Существует несколько способов получения синтетического топлива и одному из них посвящена данная статья. Замена традиционной нефти для производства моторных топлив технологиями, основанными на процессе Фишера-Тропша, позволяет значительно снизить вредные выбросы в окружающую среду за счет отсутствия вредных и токсичных примесей, в частности, серы и ее соединений. СЖТ (синтетическое жидкое топливо) имеет низкую концентрацию ароматических веществ, низкое образование бензола, парниковых газов.

Ключевые слова: синтетическое топливо, процесс Фишера-Тропша, эко-топливо

Obtaining synthetic fuel by the Fischer-Tropsch reaction

Synthetic liquid fuels (SLFs) are widely used as an alternative fuel for gasoline and diesel engines because they have strong advantages, though there are some disadvantages.

Their major advantage, determining the ecological value of fuel, is the absence of sulphur, nitrogen and aromatic compounds in them. Synthetic oil that is a mixture of C_5-C_{19} hydrocarbons of normal and iso-structure is used for processing into motor fuels, as a raw material for the chemical and petrochemical industries, or as a commercial product.

As for disadvantages of SLFs, its production demands increased energy costs. They cause the complexity of the technology and the increased investment costs, thus the cost of a coal processing plant of equivalent capacity is at least two times higher than the cost of the same oil refinery. In addition, an important problem in the production of synthetic fuels is the high-water consumption, specifically, 5-7 gallons per unit of produced fuel.

The term “synthetic liquid fuels” does not have a single definition, as different researchers use alternative approaches to its production process.

Synthetic fuel is a mixture of hydrocarbons or fuel, present from brown and hard coal or shale by destructive hydrogenation at 380-500 °C and a concentration of 10-70 MPa, gasification, followed by catalytic conversion of synthesis gas at 180-260 °C, 0.1- 2.5 MPa or semi-

coking at 500-600 °C with hydrogenation.

On the one hand, "synthetic" means that the fuel is produced artificially. The concept "synthetic" means that the fuel's production involves chemical synthesis when obtaining a higher-level chemical compound from several lower ones. This definition applies particularly to XTL fuels (raw materials in liquid), where the raw materials are first decomposed and converted into synthesis gas consisting of lower compounds (H2, CO, etc.). Then higher hydrocarbons are obtained from them (Fischer-Tropsch synthesis) [4].

It is produced on a much smaller scale than fuel from petroleum feedstocks, however, the production of synthetic fuels has the prospect of development (especially based on open coal with large production) due to limited oil reserves.

The main method of obtaining SLF is processes based on the Fischer-Tropsch process (*Fig.*).

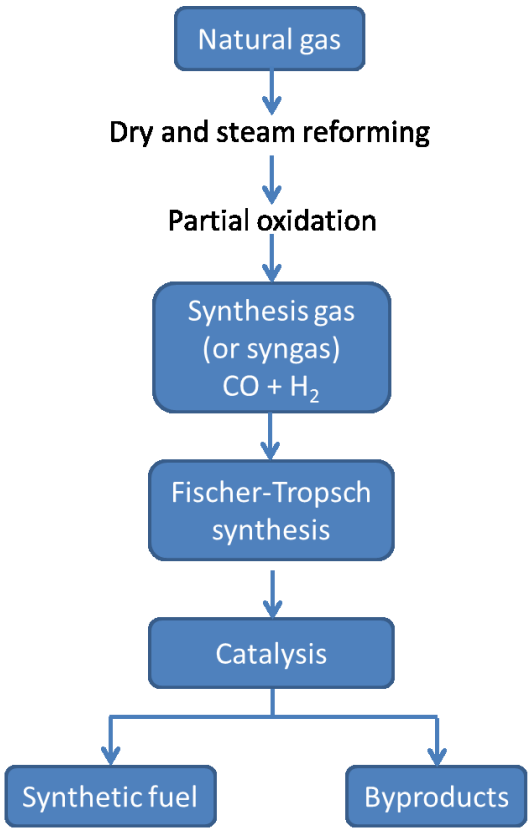

Fig. Synthetic liquid fuel production

Most synthetic fuels are produced by Fischer-Tropsch synthesis. Any organic raw materials (natural and associated petroleum gas, coal, peat, biomass, etc.) can be used in this production that are subjected to oxidative conversion and then turned into "synthesis gas".

The main task in the process of obtaining SLFs is to investigate a mixture of hydrocarbons of a certain composition with a minimum number of by–products. The solution of the problem is selecting a catalyst and optimising the process parameters [2].

Oxygen, introduced into the composition of oxides litter at the first stage of the process, is displayed on the second stage in the form of H_2O or CO_2 at the same time as the formation of hydrocarbons. There are technologies aimed at chemical use of alternative sources of raw materials. These are gas-to-liquid (GTL) processes, coal-to-liquid bone (CTL) and biomass to liquid (BTL). Fischer–Tropsch synthesis - polymerization catalytic process in protected metals of group VIII.

We are going to study production of synthetic fuel from gas. Synthesis gas is produced from natural gas via catalytic processes based on dry reforming of methane (DRM), steam reforming of methane (SRM) and partial oxidation of methane (POM). The conversion of natural gas can be carried out using oxygen (pure or in air), water or carbon dioxide as an oxidant. These reactions are described by the following equations [6]:

$$CH_4 + 1/2O_2 \leftrightarrow CO + 2H_2 \text{ (I)}$$

$$CH_4 + H_2O \leftrightarrow CO + 3H_2 \text{ (II)}$$

$$CH_4 + CO_2 \leftrightarrow 2CO + 2H_2 \text{ (III)}$$

In the case of partial oxidation of methane (Equation I), the CO/H_2 molar ratio in synthesis gas is 1 : 2. synthesis gas with an equimolar ratio of components is formed. The formation of hydrocarbons from CO and H_2 can be described by the following equation:

$$CO + 2H_2 \leftrightarrow [–CH_2–] + H_2O \text{ (IV)}$$

With iron catalysts, a significant amount of oxygenates are also formed - alcohols, aldehydes, ketones and carboxylic acids. At elevated temperatures, in the presence of zeolite co-catalysts, aromatic compounds are formed. Side reactions - direct hydrogenation of CO into me-

thane, disproportionation of CO (Bell-Boudoir reaction) and the reaction of water gas, which proceeds intensively on iron catalysts:

$$CO + 3H_2 - CH_4 + H_2O,$$

$$2CO - C + CO_2, CO + H_2O - CO_2 + H_2.$$

An overview of Chinese technology

Synthetic fuel production technologies are actively developing all over the world. More and more countries are starting to start production of SLF. As interest in the development of renewable energy continues to grow around the world, the alignment of China's capabilities and incentives to invest in the green energy sector could lead to the country's leading role in the world in this industry, so its development is worth discussing.

The main company and research and development centre for the production of synthetic liquid fuels is located in Taiyuan, Shanxi Province. Subsidiaries, Synfuels China Engineering Ltd - in Beijing, Synfuels China Catalysts Ltd - in Anhui (Inner Mongolia).

The main features of SLF production in China is that Synfuels China owns three FT synthesis technologies and actively uses its developments in production. Synfuels China is also developing an advanced FT synthesis process that is based on the partial hydrogenation of a raw material slurry under mild conditions.

According to the calculations [9], the cost of a barrel of GTL can reach $61 and $73 for the production of DCL and ICL, respectively) at a coal price of $50/t. It also follows from published data that the price of coal in the cost of GTL can be 25–45%, depending on the price of coal, the type of process, etc. This takes into account that coal is used both as a raw material and as an energy source for all plant needs (generation of electricity, steam, etc.)

The core parts of indirect coal-to-liquids (liquid fuels) technology are the Fischer-Tropsch (F-T) synthesis process, F-T catalyst and reactor technologies. Its advantages and characteristics are able to convert any combustible carbonaceous organic matter such as coal and biomass to high-quality oil products and raw chemical materials, through gasification, purification and synthesis, providing a feasible technical route to produce organic hydrocarbons from biomass (renewable resources). Based on the technical development trend of indirect coal liquefaction processes and application of F-T synthesis in biomass conversion(especially residue), Synfuels China mainly focuses on innovative R&D on indirect coal-to-liquids (oil products and chemicals), and carries out research on the integration of indirect coal liquefaction, low-temperature carbonization, multistage liquefaction, and gas turbine power generation, in order to improve the overall energy conversion efficiency of coal liquefaction process. Meanwhile, Synfuels China is working on biomass gasification technology and demonstration projects, and actively promoting the application of F-T synthesis technology for the conversion of biomass [6].

An overview of African technology

African companies are also developing synthetic fuel production, initially involving the western developments.

At the beginning of the 20th century, Germany was under sanctions. Germany did not have its own oil, therefore the development of technology for producing fuel from coal was supported by the German government. As a result, in 1919 the technology was developed, and in 1934 the first industrial plant was already operating.

Since the production of synthetic fuels is expensive, immediately after the defeat of Germany and Japan in World War II, this industry ceased to exist.

After that, the group of German scientists moved to the Republic of South Africa. Meanwhile, South Africa separated illegally from the British Empire (as the British then believed). South Africa came under political sanctions and did not receive gasoline from Britain anymore. Thus, the government established the “South African Synthetic Oil Company”. It brought the synthetic fuel industry and the Fischer-Tropsch process to a new level in South Africa in the 1950s.

African Synfuel uses coal and some specific features for its production.

Sasol is a business that includes two different directions. Such as the chemical industry and energy. The chemical business is built with growth in mind, meeting the growing needs of

consumers, including the needs of a growing and urbanising middle class. It will focus on special chemicals, where it has differentiated capabilities and a strong market position that can be expanded over time.

This business has a wide range of integrated alcohols and surfactants, alumina specialty products that are heavily backed by a track record of collaborative innovation with customers.

24 August 2005 Sasol has produced almost 1,5 billion barrels of synthetic fuel from about 800 million tonnes of coal since the first sample of synthetic oil from coal was produced fifty years ago at its Sasolburg plant near Johannesburg in South Africa on 23 August 1955.

Regarded as a world technology leader in the production of coal-to-liquids (CTL), Sasol operates the world's only commercial scale synthetic plant at Secunda, where it produces 150 000 barrels of liquid fuel per day.

Sasol currently supplies about 28% of South Africa's fuel needs from coal, saving the country more than R29 billion (US5,1 billion) a year in foreign exchange.

Their portfolio of agro-chemicals additives is tailored to meet new market trends and regulatory requirements. Also, their alcohols, surfactants, waxes and solvents are enabling performance optimisation and safer application of crop protection, soil and plant nutrition, and tank-mix adjuvant formulations.

Perspectives of the technology in Europe and World

Nowadays, such huge companies like "Porsche" are developing production of synthetic fuel. We suppose such an approach means that investments in this sphere will inevitably rise rapidly.

in Punta Arenas, Chile, a pilot plant funded by "Porsche", "Siemens Energy" and "ExxonMobil" was built. "Porsche" then announced that it would invest $75 million to buy a 12.5% stake in the start-up. Long-term plans include the construction of 12 plants with a total cost of $50 billion each. according to Haru Oni, capturing 2 million metric tons of CO2 per year. [7]

As volumes of manufacture increase, Porsche plans to use synthetic fuel for their new gasoline cars as an initial filling. Synfuel is tested in motorsports. Thus, Formula 1 might become a consumer of the synfuel in 2026 and now negotiations about that are being held between "Ars" and "Porsche". Not only cars are potential consumers of the synthetic fuel. Also, it is possible to fill heavy vehicles like tracks, aeroplanes and ships with such carbon neutral fuel.

Conclusion

World experience shows that the technology for synthetic oil production will still be developed in the near future and, probably, such oil will gradually replace the natural one. Synthetic fuels have a number of benefits that can be found in various industries.

The results of the research:

1. The main stages of obtaining synthetic fuel have been elaborated with respect to GTF (gas-to-fuel) technology.

2. An overview of the global production of synthetic fuels has been made and global trends in its implementation have been observed. Observing the global market, we can find that synthetic fuel is expected to be a fuel of the future. Many countries are starting to launch the production of synthetic liquid fuels, which will contribute to the development of this technology.

In this study, we looked at some ways to produce synthetic fuels. We have discovered that the most widely spread and energy-efficient is CTL (coal - to - liquid) technology. Also, some of BRICS countries like Africa and China use this technology because of the geographical location and access to special resources.

It is also worth considering the tendency of increasing investment in this area by the European community, as this is a significant product for them. Since the gasoline production is a cheap – transport complex will not switch to the SLFs. Though the production is expensive, some countries and huge European companies support the development of Synfuel. Further, global transition to synthetic fuels instead of conventional gasoline will reduce the volume of CO_2 and decrease the greenhouse effect.

Список источников

1. Басин А. Д. Получение синтетического жидкого топлив**а** // X Всероссийская, научно-практическая конференция молодых ученых с Международным участием «Россия Молодая» (Кемерово, 24–27 апреля 2018 г.). Кемерово: Изд-во Кузбасский государственный технический университет имени Т. Ф. Горбачева. 2018.
2. Крылова А. Ю. Катализаторы синтеза Фишера-Тропша – ядро стратегии получения синтетических жидких топлив // Кинетика и Катализ. 2012. № 6. 790 с.
3. Советин Ф. С., Гартман Т. Н., Панкрушина А. В., Асеев К. М., Павлов А. С. Обзор технологий синтетического жидкого топлива из природного газа // Успехи в химии и химической технологии. 2021. № 8. С. 139–142.
4. Nauka.relis.ru. Получение топливного газа для теплоэнергетики и синтез-газа для переработки его в синтетические жидкие топлива газификацией твердых топлив. [Электронный ресурс]. URL: https: // xn--80aeg0cdgk.xn--p1ai/pribory-dlya-tepla/sintez-gaz-iz-uglya.html (01.04.2022).
5. Denny K. S. Ng, Kok Siew Ng, Rex T. L. Ng Encyclopedia of Sustainable Technologies. 2017. Pages 299-314.
6. R. Rauch H., Hofbauer S., Sacreanu A. Chiru From gasification to synthetic fuels via Fischer-Tropsch Synthesis. Bulletin of the Transilvania University of Braşov Vol. 3 (52). 2010 Series I: Engineering Sciences.
7. Jaclyn Trop. Porsche hits the gas on synthetic fuel with $75M investment. April 6, 2022. [Available from]. URL: https: // techcrunch.com/2022/04/06/porsche-synthetic-fuels-investment-sports-cars/amp/ (20.04.2022).
8. Alex Anderson Sasol produces 1,5 billion barrels of synthetic fuel from coal in fifty years [sasol company official]. [Available from]. URL: https://www.sasol.com/media-centre/media-releases/sasol-produces-15-billion-barrels-synthetic-fuel-coal-fifty-years (18.04.2022).
9. Dr. Li Yongwang, Mr. Zhang Donghai. Synfuel China. [Available from]. URL: http://www.synfuelschina.com.cn/en/about/#:~:text=Synfuels%20China%20Huainan%20Catalyst%20Co.%2C%20Ltd.&text=was%20founded%20in%20December%202006,technical%20services%20on%20catalyst%20production(18.04.2022).

Информация об авторах / Information about the Authors

Svetlana V. Latysheva,
Candidate of Philologyy, Associate Professor,
Head of Humanities Department,
Baikal School of BRICS,
Irkutsk National Research Technical University,
83 Lermontov St., Irkutsk 664074,
Russian Federation,
svlatysheva@ex.istu.edu

Светлана Владимировна Латышева,
кандидат филологических наук, доцент,
Директор департамента гуманитарных наук,
Байкальский институт БРИКС,
Иркутский национальный исследовательский технический университет,
664074, г. Иркутск, ул. Лермонтова, 83,
Российская Федерация,
svlatysheva@ex.istu.edu

Roman S. Maslennikov,
Student,
Power Electrical Engineering,
Irkutsk National Research Technical University,
83 Lermontov St., Irkutsk 664074,
Russian Federation,
romaslennikoff@gmail.com

Роман Сергеевич Масленников,
студент группы ЭПАб-21-1,
Байкальский институт БРИКС,
Иркутский национальный исследовательский технический университет,
664074, г. Иркутск, ул. Лермонтова, 83,
Российская Федерация,
romaslennikoff@gmail.com

Denis A. Studennikov,
Student,
Power Electrical Engineering,
Irkutsk National Research Technical University,
83 Lermontov St., Irkutsk 664074,
Russian Federation,
denis.studennikov@icloud.com

Денис Александрович Студенников,
студент группы ЭПАб-21-1,
Байкальский институт БРИКС,
Иркутский национальный исследовательский технический университет,
664074, г. Иркутск, ул. Лермонтова, 83,
Российская Федерация,
denis.studennikov@icloud.com

Danil M. Volygin,
Student,
Power Electrical Engineering,
Irkutsk National Research Technical University,
83 Lermontov St., Irkutsk 664074,
Russian Federation,
danvolgyan@gmail.com

Данил Максимович Волыгин,
студент группы ЭПАб-21-1,
Байкальский институт БРИКС,
Иркутский национальный исследовательский технический университет,
664074, г. Иркутск, ул. Лермонтова, 83,
Российская Федерация,
danvolgyan@gmail.com