POWER TECHNOLOGY COMPLEX FOR PRODUCTION OF MOTOR FUEL FROM BROWN COALS WITH POWER SUPPLY FROM NPPs

M.F. TROYANOV, V.M. POPLAVSKIJ, G.I. SIDOROV, A.V. BONDARENKO, A.N. CHEBESKOV, V.N. CHUSHKIN, A.A. KARABASH
State Research Center of Russian Federation — Institute of Physics and Power Engineering, Obninsk

A.A. KRICHKO, A.S. MALOLETNEV
Combustible Resources Institute,
Moscow

Russian Federation

Abstract

With the present-day challenge of efficient use of low-grade coals and current restructuring of coal industry in the Russian Federation, it is urgent to organise the motor fuel production by the synthesis from low grade coals and heavy petroleum residues. With this objective in view, the Institute of Physics and Power Engineering of RF Minatom and Combustible Resources Institute of RF Mintopenergo proposed a project of a standard nuclear power technology complex for synthetic liquid fuel (SLF) production using fast neutron reactors for power supply. The proposed project has two main objectives: (1) Engineering and economical optimization of the nuclear power supply for SLF production; and (2) Engineering and economical optimization of the SLF production by hydrogenisation of brown coals and heavy petroleum residues with a complex development of advanced coal chemistry. As a first approach, a scheme is proposed with the use of existing reactor cooling equipment, in particular, steam generators of BN-600, limiting the effect on safety of reactor facility operation at minimum in case of deviations and abnormalities in the operation of technological complex. The possibility to exclude additional requirements to the equipment for nuclear facility cooling was also taken into account. It was proposed to use an intermediate steam-water circuit between the secondary circuit sodium and the coolant to heat the technological equipment. The only change required for the BN-600 equipment will be the replacement of sections of intermediate steam superheaters at the section of main steam superheaters. The economic aspects of synthetic motor fuel production proposed by the joint project depend on the evaluation of integral balances: thermal power engineering, chemical technology, the development of advanced large scale coal chemistry of high profitability; utilisation of ash and precious microelements in waste-free technology; production of valuable isotopes; radical solution of ecological problems.

Nuclear Complex Project for Synthetic Liquid Fuel Production

With the present-day challenge of efficient use of low-grade coals and current restructuring of coal industry in the Russian Federation, it is urgent to organise the motor fuel production by the synthesis from low grade coals and heavy petroleum residues.

With this objective in view, SSC RF – Institute of Physics and Power Engineering (IPPE) of RF Minatom and Combustible Resources Institute of RF Mintopenergo (CRI) proposed a project of a standard nuclear power technology complex for synthetic liquid fuel (SLF) production using fast neutron reactors for power supply.

Fast reactors with liquid metal coolants developed at IPPE have sufficiently high thermal power generation potential requiring the technological processes with low pressure in coolant. More than 20-year experience of successful operation of fast reactors at commercial NPPs has shown that they are highly reliable and safe.

The proposed project of a standard nuclear power technology complex for SLF production has two main objectives:

1) Engineering and economical optimization of the nuclear power supply for SLF production;
2) Engineering and economical optimization of the SLF production by hydrogenisation of brown coals and heavy petroleum residues with a complex development of advanced coal chemistry.

Each of these aspects appears to be a multi-factor task.

The first major aspect is directly associated with the general strategy of nuclear power development in the country, considering its present and perspective structure. The central problem here is the choice of an appropriate type of reactor, nuclear fuel, and the optimal nuclear fuel cycle (NFC). It is coordinated with the strategy of the nuclear power perspective development and the optimization of NFC in Russia (closed NFC with fast reactors involved) [1]. Safety and ecological compatibility are issues of primary importance in the development of the standard nuclear power technology complex for SLF production.

The second major aspect of the project is considered as below.
Essentially, motor fuel synthesis by coal hydrogenization is a process to transform high-molecular substances of coal organic mass (COM) into liquid and gaseous hydrocarbons by pressurized hydrogen. This approach appears to become attractive for the heat power engineering world when the prospective exhaustion of natural gas and oil resources is considered. The scientific fundamentals of this process were developed in the early 20th century by various scientists - V.Ipatyev, N.Zelinski, F.Bergius, F.Fischer, and others.

Technological Background of Synthetic Liquid Fuel Production

In 1930s, industrial enterprises were founded in several countries, in particular, Germany and Great Britain, for the production of petrol, kerosene, diesel fuel, lubrication oil, etc., by coal hydrogenization. In 1950s, coal hydrogenization was developed to the commercial scale in the USSR as well. However, when new oil fields were found in the USSR, Near East countries, etc., the oil prices decreased, and SLF production from coal virtually ceased. In 1970s, the oil price rose sharply, and it became evident that resources would be exhausted in the near future.

It has been recognized world-wide that coal liquefication is a promising method of obtaining liquid motor fuel and diverse products for chemical industry with the raw material resources available for this purpose for a long prospect. To date, in industrialized countries, especially in the USA, facilities and experimental plants for coal liquefication have been operated with their production of more than 21 million tons of SLF a year; 15 basic technologies are supported by intensive R&D work; more than 50 projects of the total annual design output of about 300 million tons of SLF have been launcehed at various stages of development and construction [3].

Brown coals are the best raw material for synthesizing a wide range of motor fuels. Low metamorphization solid combustible minerals of this grade is typified by a small extent of carbonification and a peculiar composition of organic mass components. Brown coals are considered to be low-grade power fuel; however, there are extremely valuable raw materials for coal chemistry. This is confirmed by several examples in Germany in 1930s to early 1940s, where very strong industrial concerns developed on the ground of the domestic brown coal resources before the war. Russia's resources of brown coal are the largest in the world. A giant deposit of high quality brown coal (exceeding trillion of tons), the world's cheapest chemical raw material, serves as a unique base of the Kansky-Achinsky Fuel and Energy Resource Complex (KAFRC), its implementation being given the prime importance in the State Programmes of Siberia development.

Specific features of the composition and structure of these brown coals containing 5-10% ash and up to 40% moisture, their non-transportability and extreme cheap cost of mining (10% of the coal cost in Donbass) give some specific features of operational coal-fueled large thermal electric power plants of the KAFRC (Nazarovski, Berezovski). First of all, this causes an extremely hazardous ecological impacto on that vast region.

The brown coal basin in the Moscow area (Tulaugol) has been exhausted for its long exploitation. Due to a high ash content in that coal (up to 40%), many mines have been closed. However, instead the oil-refineries in the European region of Russia have at their disposal a valuable raw material - heavy petroleum residues which can be reprocessed into standard motor fuel by the hydrogenization method.

Since the laboratory of fuel hydrogenization was established at CRI in 1934, it has carried out a lot of work on this subject. As a result of fundamental research, the scientific basis has been established for solid fuel hydrogenization processes. The theory of hydrogenization transformation of hydrocarbons has been developed. The chemical behaviour and kinetics of catalytic reactions have been identified over a wide range of conditions. New effective catalysts have been created. Principle regularities of hydrogenization reactions of high-molecular compounds have been formulated.

In 1970s, CRI developed technologies for obtaining motor fuel from coals using the hydrogenization method under medium pressure of hydrogen (up to 10 MPa) [4]. The new technology has basic advantages compared to the processes used till then in foreign countries. The main challenge in the technology improvement has been met: decrease of pressure in coal hydrogenization from 30 to 10 MPa and even lower levels. More than 30 inventions have been realized. The pressure decrease made it possible to lower the capital investments approximately by 5 times, using the machine building base in existence now for the manufacturing of the main devices, chemical reactors, and complete lines equipped with high production capacity.

The technology proposed by CRI has an important advantage: being universal, it enables equally efficient synthesis of standard (qualified) motor fuels, using a uniform technological regime and one equipment line, both from the cheapest brown coals and from heavy oil residues (fuel oil, residual tar) which are available in excessive quantities. The CRI technological process is waste-free. Its major advantage is the possibility to obtain the most valuable additional sources of chemical raw materials for chemical industries such as phenols, nitrogen bases and other additional sources of chemical raw materials.

In this aspect, the CRI process for obtaining synthetic motor fuels is fundamental also for the development of advanced large scale coal chemistry. The technology developed provides a rational use of coal ash for the production of building materials; recovering a variety rare, scattered, and precious elements, such as germanium, gallium, yttrium, scandium, mercury, arsenic, natural radioactive elements of the uranium and thorium group, etc., which are geochemically associated in brown coals. In the conventional burning process of coals at thermal power plants, these elements are dispersed in the gas releases, and the ash is concentrated in large masses and pollutes wide areas.

The technology developed by CRI for motor fuel synthesis by hydrogenization of brown coals and heavy petroleum residues has undergone long-term and careful tests under the quasi-industrial conditions at the experimental plant ST-5 of synthetic fuel at Venev, Tula. The new technology effectiveness has been widely recognized by the scientific and expert community.

In 1992, CRI and R&D Institute for Gas and Petroleum Industry (Grozgidroneftekhim) performed a joint feasibility study of constructing an industrial enterprise for the production of motor fuel from the KAFRC brown coals with annual output of 3 million tons. The project was approved by the Mintopenergo. The KAFRC brown coals are the most suitable for the conditions of technology developed by CRI for synthetic liquid fuel producdtion. In the hydrofining of products of the liquefied coal, the ST-5 plant produced components of petrol and diesel fuel which meet the state standards for high-quality oil products.

The project of the nuclear power and technology complex proposed for the production of synthetic motor fuel relies on all achievements in the technology of motor fuels by hydrogenization of brown coals and at the same time is typified by a principle novelty: power supply for all hydrogenization processes by fast reactors. As mentioned above, these technologies of CRI are most efficiently combined with fast neutron reactors with liquid metal coolant, with thermal energy potential reaching 550°C, which is enough to meet the demand of all steps of technological process of SLF production [5-8].

Energy Source for Synthetic Liquid Fuel Production

To obtain one ton of the product (SLF), a thermal power plant has to burn 1.5 – 2 tons of organic fuel, which results in a two-fold increase of expenses for the coal mining and withdrawal of lands from economic use.

In a large-scale production of SLF, ecology-related issues are especially important. Comparative analyses of the general inpacts for public health caused by the operation of nuclear and coal fuel cycle enterprises calculated for equal annual energy yields gives at least a 100-fold advantage to the nuclear fuel cycle (N.Ponomaryov-Stepnoi, "Novy Mir" – New World monthly, 1988, 9, p. 173). The inclusion of ecologically safe nuclear reactors(BOR-60, BN-350, BN-600, BN-800 types) into a commercial complex for the SLF production, electric energy, water steam and gas coolant would allow to reduce the consumption of coal and power source gas by 80%.

The structure of power consumption of the technological complex is characterized as follows: key equipment of the synthetic liquid fuel production line (paste preparation, separation, production of vacuum gas oil, cracking of middle oils, hydrofining, treatment, reforming, distilling) consumes the heating media's heat with temperature potential exceeding 430°C. Its fraction in the general balance is ~30%, if the initial moisture content of the coal amounts to 30%. Heat with lower temperature potential can be used to generate electricity, and to obtain steam that is subsequently delivered for the facility's technologic processes (technological steam), coal preparation and drying of the coals being processed. The required ratio of the high- and low- potential heat in the SLF production scheme can be provided by a fast reactor, which has the cooling metal temperature at the reactor inlet at ~320°C, and at the outlet at ~530°C.

From the standpoint of SLF production, such schemes can provide its maximum possible yield per unit power of reactor. If reactors in operation, e.g., BN-600 are strategically used for the project, the schemes would require the development of new heat exchangers from the secondary circuit sodium to the coolant for the technological equipment (cooling of secondary circuit sodium from ~520°C to ~440°C), and new steam generators for supplying heat to the equipment for technological steam production, coal preparation and drying, and to the electric generation to meet the demand of the technologic facility itself.

As a first approach, a scheme is proposed (Fig.2) with the use of existing reactor cooling equipment, in particular, steam generators of BN-600, limiting the effect on safety of reactor facility operation at minimum in case of deviations and abnormalities in the operation of technological complex. The possibility to exclude additional requirements to the equipment for nuclear facility cooling was also taken into account. It was proposed to use an intermediate steam-water circuit between the secondary circuit sodium and the coolant to heat the technological equipment. As the intermediate heat media, inert gas was used for coal heating and drying, and technical water was used for obtaining technological steam. The closed circuit of the steam generator cooling maintains the water quality required for reliable operations of the steam generator. The water-steam cycle in the intermediate circuit is similar to the tertiary circuit of BN-600. This leads to the situation in which thermal potential of the secondary circuit

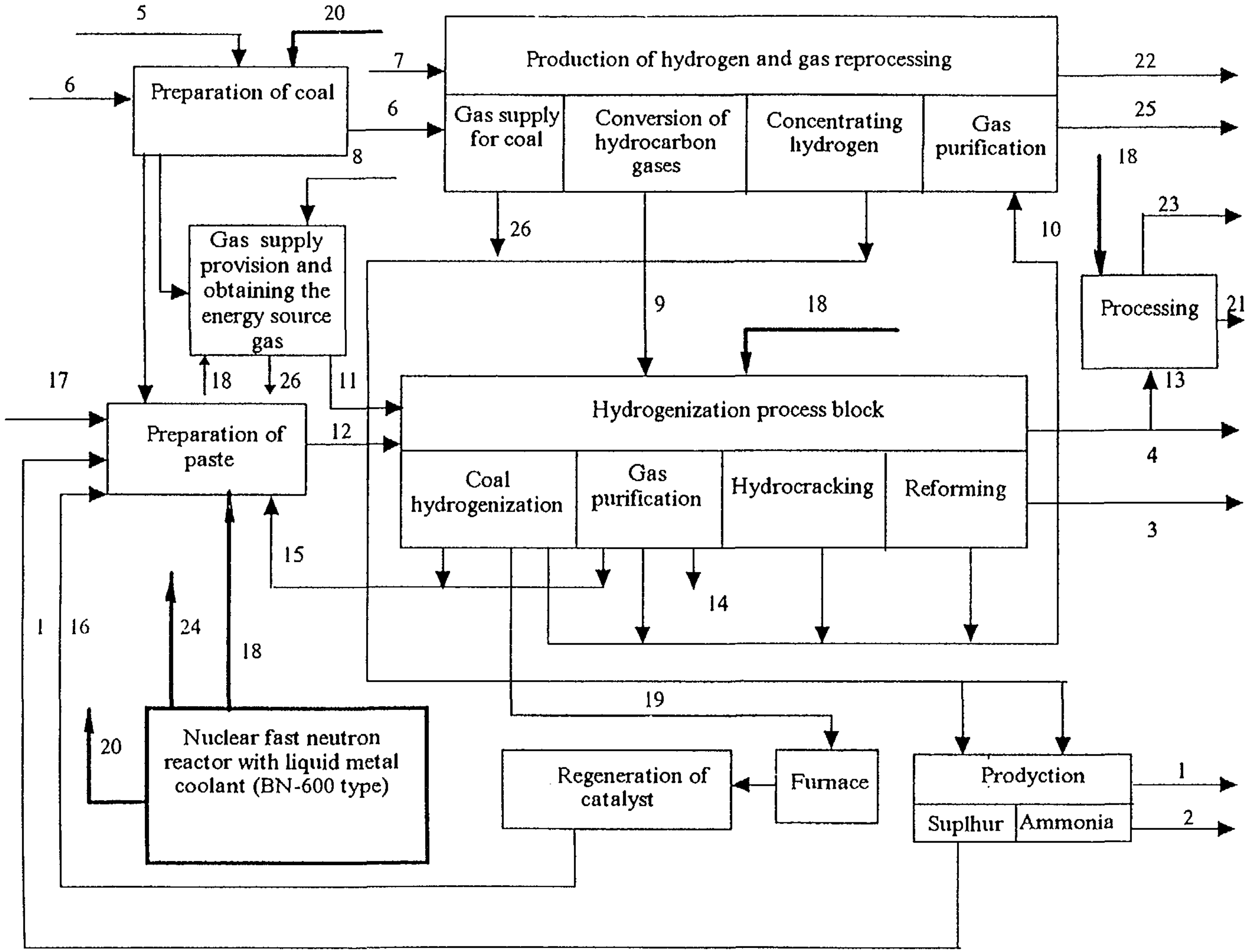

Fig.1
Principle flow chart for obtaining liquid product fromcoal at industrial enterprise with nuclear source of BN-600 type

1 - Sulphur
2 - Ammonia
3 - High octane petrol
4 - Diesel fuel
5 - Reagents
6 - Coal
7 - Oxygen
8 - Air
9 - Hydrogen
10 - Gas
11 - Energy gas
12 - Paste
13 - Low octane petrol
14 - Water
15 - Paste forming source
16 - Return of catalyst
17 - Catalyst
18 - Vapor
19 - Slag
20- Hot inert gas
21 - Automobile petrol
22 - Liquified gases - C_3 - C_4;
23 - Aromatic hydrocarbons - C_6-C_8;
24 - Electric energy
25 - CO_2
26 - Slag

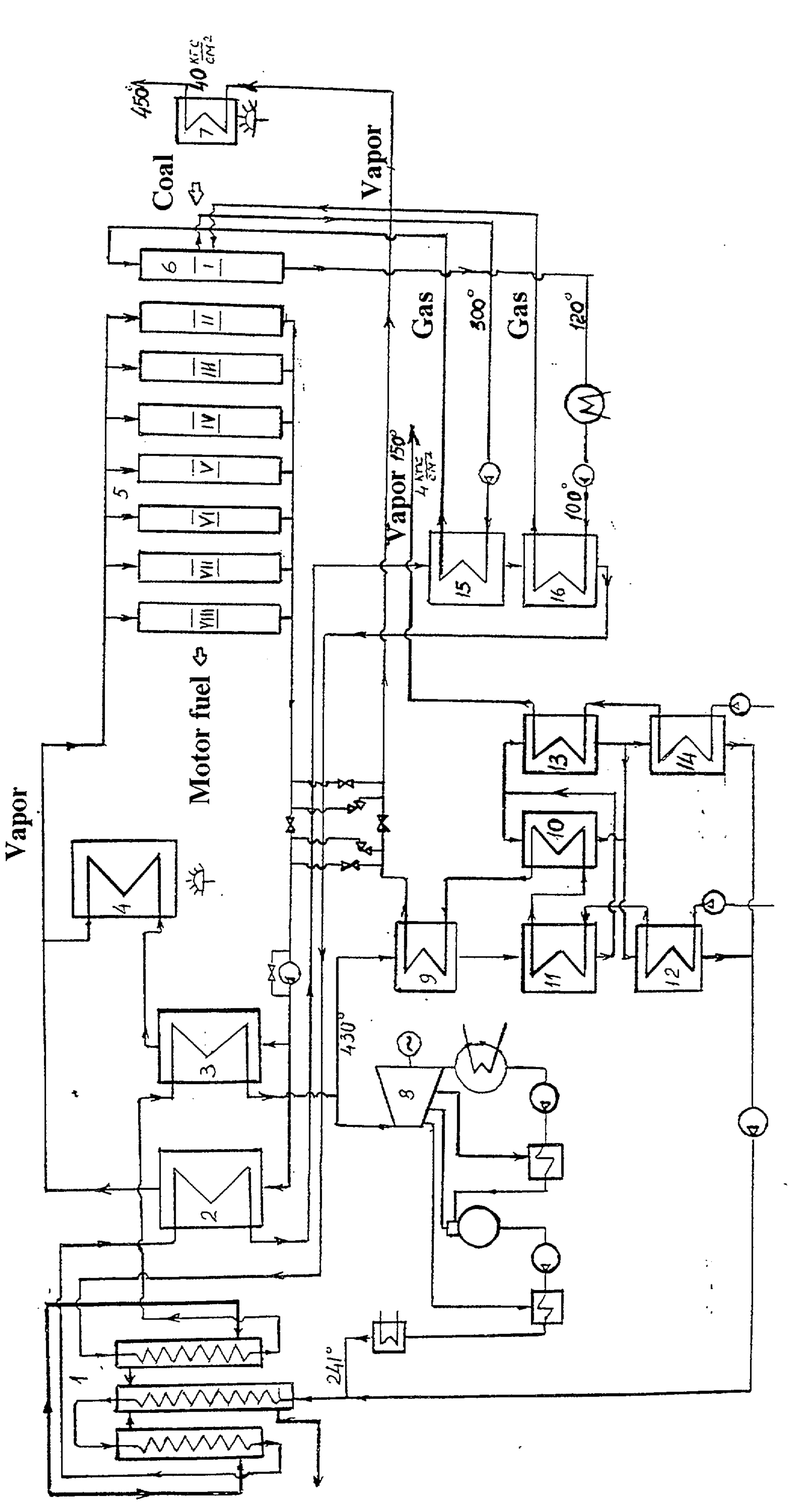
Vapor
Motor fuel
Coal
Vapor
Gas
300°
Gas
120°
100°
Vapor 150°
430°
241°
450°
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
I
II
III
IV
V
VI
VII
VIII

Fig. 2

sodium with temperature above 430°C cannot be used for the power supply of technological equipment only (~60%), since it reduces the SLF production rate per kilowatt of the reactor power. Because the high pressure steam at temperature of 430°C exists in the intermediate circuits in excess of the need for the technological cycle, it can also be used to generate electricity considerably above the need of technological facilities.

Structural scheme of the nuclear power complex based on BN-600 is presented in Figs. 1 and 2.

Designations in Fig. 2 are as follows:
1 – steam generator; 2 – heat exchanger between the steam from the steam generator superheater and the steam for heating technological equipment; 3 – heat exchanger between the steam from the intermediate superheater of steam generator – steam of the heating circuit for technological equipment heating"; 5 – technological equipment (II – paste preparation, III – separation; IV – vacuum gas oil production; V – cracking of middle oils; VI – hydrofining, VII – treatment, reforming; VIII – distillation); 6 – coal preparation, drying of coal; 7 – fire steam superheater of technological steam of high pressure; 8 – turbine generator facility for electric energy production; 9 – intermediate superheater of high pressure technological steam; 10 – evaporator of the high pressure technological steam circuit; 11 – second step heater of water of the high pressure technological steam circuit; 12 – first step heater of water of the high pressure technological steam circuit; 13 – evaporator of the low pressure technological steam circuit; 14 – water heater of the low pressure technological steam circuit; 15 – gas heater of the second step of coal preparation and drying line; 16 – gas heater of the first step coal preparation and drying line.

Principle characteristics of NPP with BN-600 reactor are presented below.

Principle characteristics of NPP with BN-600 reactor

Unit power of facility, MW:

Unit power of reactor, MW: Electric Thermal	 600 1470
Coolant temperature at the outlet of reactor, °C	550
Duration of reactor operation between reloadings, days	150
Parameters of steam generated: Temperature, °C Pressure, MPa	 505 14.2
Productivity of reactor by steam, t/h	1980
Electric efficiency (net) of reactor, %	40
Design-basis operation time, years	40

The only change required for the BN-600 equipment will be the replacement of sections of intermediate steam superheaters at the section of main steam superheaters. The reheaters' sections are not necessary to be replaced, because they are designed for operation below 3 MPa. The changeover to turbines for downgraded parameters will be required (12.0 to 13.0 MPa, 430°C, steam flow rate - ~ 500 t/h).

In the operation of the proposed scheme, the nuclear technology complex based on the power source with BN-600 will produce 8.8×10^5 t/year of SLF with the electric power supply of ~300 MW. Another yield of 170-200 MW(electric) can be transmitted to the external power network. Table 1 presents the amounts of commercial products which can be obtained from the scheme shown in Fig.3.

Table 1

Scope of production of commercial products from brown coal of KAFRC (mass. % per dry coal)

Item	
1. Petrol for vehicles	10,64
2. Jet fuel T-8B	3,19
3. Diesel fuel (S<0.05%)	28,88
4. Aromatic hydrocarbons C6 – C8	0,70
5. Methyltretbuthyl ether	2,98
6. Methanol	-
7. Sulphyr	0,07
8. Ammonia	0,40
9. Power fuel (slag of hydrogenization)	6,79
10.Phenols (phenol, crezols, resorcin, etc.)	0,70

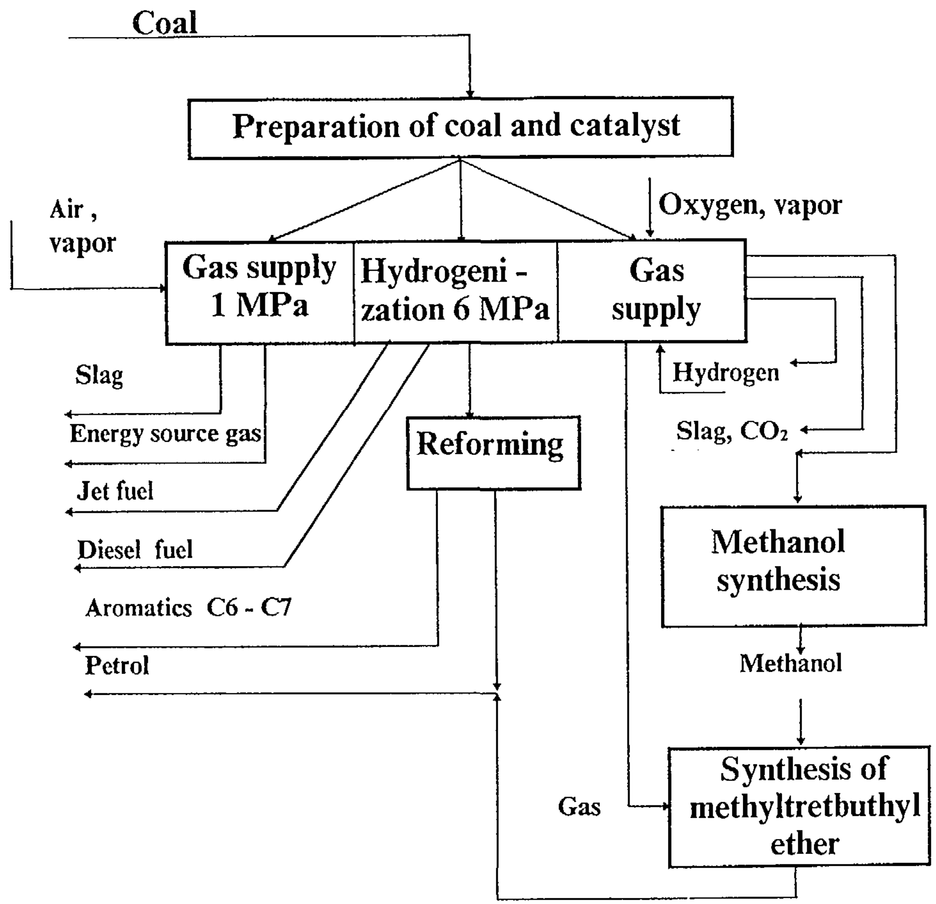

Fig. 3 Flow chart of obtaining fuel-and chemical purpose products from coal

Conclusions

The economic aspects of synthetic motor fuel production proposed by the joint project depend on the evaluation of integral balances: thermal power engineering, chemical technology, the development of advanced large scale coal chemistry of high profitability; utilisation of ash and precious microelements in waste-free technology; production of valuable isotopes; radical solution of ecological problems.

On the eve of the 21st century coal will take undoubtedly its proper place in the solution of power crisis problems in both our country and in the world.

REFERENCES

[1] Mikhailov V.N. (Minatom), Mourogov V.M., Rabotnov N.S., Troyanov M.F., Ilyunin V.G., Kagramanian V.S., Roudneva V.Ya. (IPPE, Obninsk); Solonin M.I., Zakharkin V.S., Antipov S.A., Menshikova T.S. (VNIINM, Moscow), Kiryushin A.I. (OKBM, Nizhni Novgorod). The Use of Plutonium in Nuclear Power of Russia. Book: SSC RF-IPPE, 50-years anniversary. Obninsk, 1996. P. 17-28. (Rus.)

[2] Mourogov V.M., Troyanov M.F., et al. Ecologically compatible and safe fuel cycle of the future nuclear power utilizing plutonium. IPPE, Obninsk, RF. Obninsk symposium of XV-th Mendeleev congress on general and applied chemistry. (Rus.)

[3] Wilson K.L. Coal – Bridge to the Future. M., Nedra, 1985. (Rus.)

[4] Maloletnev A.S., Krichko A.A., Garkousha A.A. Obtaining of SLF by coal hydrogenization. M., Nedra, 1992. (Rus.)

[5] Troyanov M.F., et al. Use of reactors with liquid metal coolant in motor fuel production from coal. IPPE report No 763a. 1989. (Rus.)

[6] Sidorov G.I., Gouriev V.V., Kozlovtsev V.G., Koryakin Yu.I. Using fast neutron reactors for power supply of SLF production from coal; Proceedings of the Conference of USSR Nuclear Society "Nuclear Power in the USSR" Obninsk, June 1990. (Rus.)

[7] Gromov B.F., Sidorov G.I., et al. Power supply of large tonnage productions of synthetic liquid fuels from fast-neutron nuclear power technological plant. Energeticheskoe stroitelstvo (Power construction) 1992, No. 6. (Rus.)

[8] Mourogov V.M., Troyanov M.F., Sidorov G.I., et al. Creation of the project of typical power technology complex of ecologically compatible production of SLF from coals and heavy petroleum residues. IPPE, Obninsk, RF. Obninsk symposium of XV-th Mendeleev congress on general and applied chemistry, part 1. 1994. (Rus.)