Nat. Volatiles & Essent. Oils, 2021; 8(4): 7653-7671

NVEO Natural Volatiles & Essential Oils

Eco-Friendly Brand New Energo-Technological Complexes: Ensuring Innovation-Driven Development Of Organic Energy Industry

Anatoliy A. Kosoy[1,2] , Alexandr S. Kosoi[2,3] , YuriyA. Borisov[2,4] , Eldar R.Ramazanov[2,5]

[1, 2] kosoyanatoliy@yandex.ru ORCID 0000-0002-9420-4666 Graduate Student, Assistant at the Department of "Automated control systems of thermal processes"[1] Gas-turbinetechnologies Laboratory Research Assistant[2]

[2,3]kosoyas@gmail.com ORCID: 0000-0002-1330-6231 DoctorofTechnicalScience, DirectorofDepartmentNo.10 of thermal energy sector problems[2] Director of SNPP Research & Production Centre[3]

[2,4] boricovyu@gmail.com ORCID 0000-0003-3177-7122 PhD in Technical Science, Gas-turbinetechnologiesLaboratorySeniorResearchOfficer[2] AssociateProfessoratthe Department of "Vacuum and Compressor Equipment"[4]

[2,5] christmas071@gmail.com ORCID: 0000-0002-4161-4952 Gas-turbine technologies Laboratory Research Assistant [2] Graduate Student, Assistant at the Department of "Mechanical engineering and instrumentation" of the Engineering Academy of RUDN University[5]

1 National Research University «Moscow Power Engineering Institute» 14, Krasnokazarmennaya Str., Moscow, 111250Russian Federation

2 Joint Institute for High Temperatures of the Russian Academy of Sciences 13, build.2, Izhorskaya Str., Moscow, 125412Russian Federation

3 A.A. RaspletinAlmaz RPA PJSC 80, build.16, Leningradsky av., Moscow, 125190 RussianFederation

4 Bauman Moscow State Technical University 5, build.1, 2nd BaumanskayaStr., Moscow, 105005Russian Federation

5 Peoples' Friendship University of Russia (RUDN University) 6 Miklukho-Maklaya St., Moscow, 117198 Russian Federation

Abstract

To date,concerns have been increasingly raised about emissionsofgreenhousegases (CO_2, inparticular) andglobalwarming. Oxy-fuel combustionconstitutes one of thekeytechnologiestocurbemissionsofCO_2in energy sector.Theunitswithpure oxygen-enriched fuel combustion are attractivedue to a minimum content of harmful admixtures in the oxy-fuelcombinedcyclegasturbineunits (OCCGTUs) exhaust gas. Wastefluidtherewithcontainsmostlyvapours ofwaterandcarbondioxide, and only CO_2 remains after water condensation.

For a unitwithoxy-fuelcombustion,thecompressor-lesscombinedcyclegasturbineunitisconsidered, where,in the liquid phase, pumping equipment increases pressure of all fluid components prior to their supplying to a combustion chamber.There is a description of theprocessflow diagram (PFD) ofthesuggestedunitthat employsorganicRankinecycle(ORC), which substantially augments (by about 5 absolute percent) the unit efficiency factor (EF). Potentialadvantagesof compressor-less combined cycle gas-turbine unit have been presented.

Thearticleexaminestheprospectsofusingthesuggested PFD in energo-technological complexes of different types. The "ArcticCascade" Projectwithcompressor-lesscombinedcyclegasturbineunitandintegration ofthepower-producing unitthermodynamic cycle with theliquefied natural gasplant (LNG-plant) bring considerableeconomic andenvironmental benefits.

It is necessary to widen the searches forinnovativeconcepts of creatinghigh-efficiencypower-producingunitsto the systems, that take into accountenergy production preparation, and energy generation, potentialcombination with processcyclesandmanufacture ofchemical products, andutilisationofproductionwaste as well.

Keywords: carbon capture,oxy-fuel combustion, compressor-less combined cycle, organic Rankine cycle, air separation unit, liquefied natural gas

1. Introduction

Itisbeyondquestionthatcreationofzero-carbonglobaleconomywillattainakeyposition for the nearest decades. The recognised principalaspects of this task involve climate and ecology, and their interrelation and influence on the biosphere have become increasingly prominentevery year. Moreandmorescientists, politicians, andpublicorganisationsstate that there is a need for a radical transition ofhuman activities toeco-climaticallysafetechnologies. Theentirecycleofactivities is considered therewith, asthesayinggoes: "fromore, takingallside effects into account".Now, theendproductpriceindexalsoincludes "natural" consequences of its production, the whole lifecycle, involving utilisation.Redindicatorsoftheseindicesbecomethemostimportantaspectsofnotonly moral but legal prohibition of using the entire number of technologies habitual for us, what is most pronounced in power sector.

Itis commonly known that electricpowerindustry is multifaceted and diverse. Thermal, helio-, nuclear, wind, hydro-, hydrogen, emission, chemical,autonomousandintegrated, small, big, local, green, etc. types are found in the literature. Inrecentyears,the adjectives"renewable" and "green"are considered a compliment, and "thermal" soundsabusive, an assault on the ears.A sustained note in mass media of the early 21stcentury: solar batteriesarepraised, andthe plans to closecoalandnuclearpowerplants are reported.Aswift declineinorganicfuel-based energy industry has been predicted. Carbondioxideemission – greenhousegas, greatlyaffectingtheEarth'sclimate, is the major argument here.Legislativeinitiativesto bannotonlygenerationofelectricityusing organicfuel, but also its purchase, have been introduced.From 2022, Europeplans to introduce a crossborderlevyfor carbonimports. Moreandmoreelectricenergyhasbeenproducedfromrenewablesources, with prevailing percentage of this generation throughinstallingsolar arrayson the roofs ofresidential, commercialandindustrialbuildings, i.e., small and medium, rather than large solar power stations, occupying vast land areas.AccordingtotheInternationalEnergyAgency (IAE),evenby 2025 the percentage ofrenewableenergysources (sun, wind, water, andbiofuel) in global electrical energy generationwill reach30% [1].

Still, iseverything so unambiguouswith no options in the problem of using in power sector the organicenergyresources, Russiaisextremelyrichin?

First and foremost, we shall recall somefeaturesof andconventionalapproachesto usingorganicfuelinpowersector. InRussia,asinmostcountriesofthe world,electric powerplantsonorganicfueltend to predominate nowadays. TheabsolutevalueofCO$_2$ emissionbytheseplants, equivalent to about a quarter of allman-madeemissionsofcarbondioxidegas, is related to fuel combustioninthermalmachinery, anddependsonthefuelcalorificvalueandthe efficiency of the machinery itself.Thus, comparingcoalandhydrocarbonmethane, thelatteris obviously more advantageous owing to ahighercalorificvalue. Inaddition, thereislesscarboninmethane, andwaterisknown to be producedas a result of the methane hydrogen oxidation reaction.In this context,purehydrogenhasan evengreateradvantageasafuel. Although, taking into account the expenses incurred duringthehydrogenproductioncycleanditsstorage, these advantagesare then ambiguous.

1.1. Efficiency indicators ofpower-generatingunit

There is also no unambiguousanswerin the case ofthermalmachinery. Here, the efficiency of electric generatingunit is defined by numerous factors. Combustion ofnatural gasincombinedcyclegasturbineunits (CCGTUs) is known to be the most cost-effective. However, it should be made clear as well. Hence, in RussiaCHPPswithconsiderablecogenerationloads(meanrelativeratiobetweencentralisedheatgenerationandelectricenergyis 1.46) are frequent. “Classic” CCGTU–agas-turbineunitwithsteam-turbineRankine cyclewaste-heat loop,employed at the CHPP, offers no optimal solution.Using “classic” CCGTU as a power unit forsometechnologicalcomplexesofchemicalindustry is also not optimal [2].

Itshouldbementionedthatthe efficiencyfactor (EF), a widely recognizedindicatorof the efficiencyofthermalequipment, is not its absolute characteristic.EFdefinestheequipment capability for convertingthefuelchemicalenergytomechanicalenergy; a considerable portion of heat energy conversion is left out.Furtheractionsfor converting the energy, produced by the equipment,to therequiredelectricity, orothernetenergyhavealsobeenleftaside. Thus, in case of the above-mentionedcogenerationCHPPmode, there arecharacteristics,that makeEFmore precise, more exactly defining theefficiencyofthe equipment operated in heat-end mode (1, 2),and the units themselves, which ensure such a consumer’s dualitywithmaximumefficiency, are calledcogeneration units.

CFU = $(N_e + Q_t)/H_t$,(1)

where:

CFU – coefficient of fuel utilisation;

N_e – effective electric capacity;

Q_t – suppliedthermal capacity;

H_t – total energy of consumed fuel.

$\eta_e = N_e / (H_t – Q_t / \eta_b)$,(2)

where:

η_e–EFofheat-endmode electricenergygeneration;

N_e – effective electric capacity;

Q_t – suppliedthermal capacity;

H_t – total energy of consumed fuel;

η_b – EF ofheating boiler.

CFUandEFare very informative for multipurposeplants, whichproduceextramarketproductsin addition toelectric energy. CFUdemonstrateshighefficiencyofcogenerationandtrigenerationascomparedtoseparateproduction ofelectricenergyandthe very same heat and cold.InRussia, cogenerationpowerunitshavebeen rather extensively applied.There are projects ofcogenerationCCGTUswith averyhighefficiency, due to high values of initial cycle parameters and potential use of low-temperatureheatoffluegases, includingcondensation heat ofwater, formed during fuel combustion [3-6].Of note also is a recent growing interestintrigenerationunits, which providecomplexgenerationofelectricity, heat, andcold. From the middle of the past century,similar to them integratedenergo-technologicalcomplexes have been used in chemical industry.Nowadays,cogenerationandtrigenerationprojectshavebeenofferedforgasindustry,whichallowor ganicfueltobeusedfairlyefficiently, and CO_2greenhousegasemission to the atmosphere to be thus reduced[7].

Even so, with allobviousefficiencyofmentionedcogenerationandtrigenerationunits,the problem ofcarbondioxide sequestering for them still remains unsolved. The attempts to create a devicecapable ofefficientlycapturing$CO_2$from the heat engine exhaust gases(Post-combustioncapture - PostCC) are still unsuccessful.Here, of importance are thecostsofthecomplete end-to-end PostCC cycle, includingproduction ofliquid CO_2, convenient for storing, transporting, using, and burying [8].A system of removingCO_2prior to combustion (so called system of Pre-combustion Capture) can provisionally facilitate solving this problem. The process implies methane conversion to the previously mentionedhydrogen andcarbon dioxide, withfurtherextractionandcombustionofpurehydrogenin the thermal equipment. Abroad, such treatment is estimatedat 60…30$ per a tonne of CO_2 [9], although these numbers do not includefurther expenses associated with gaseous stateofcarbon dioxide.

2. State of the art

Surely, there is no point in analysing the entire range ofpossible combinations of devices inpower-producingunitsintermsofCO_2sequestering. Only themostpromisingsolutions will be mentioned.

The last decades have seen an intensification of works on theCCGTUprojectswithcombustion oforganicfuelinoxygen (OCCGTU). Inthe 21stcentury, the research and practice development of the formerly knownanaerobic (air-independent) powerunitsofsubmarineshas been underwayin theland-based power industry as the unitsthat ensure a complete capture ofCO_2 [10, 11]. One of the most frequent in the literaturedescriptionsofhowsuchOCCGTUsfunction, isasocalledthermodynamicAllamcycle, based on which first power stations inUSAhave already been built [12]. Theseunitsareattractivebecause of minimum content of harmful admixturesintheOCCGTUexhaustgases. Wasteworkingfluidtherewithcontainsmostlyvapoursofwaterandcarbondioxide, andonlyCO_2(provided that there is nosulphurandotherharmfuladmixturesintheprimaryfuel)remainsafterwatercondensation. A required amount of CO_2, withdrawnfromexhaustgases, is supplied to the combustion chamber of the unit with suchthermodynamiccycles,inadditiontoorganicfuelandoxygen, as a dead matter, to create an acceptable for the turbine gas temperature. In this context, theAllamflowdiagramofOCCGTUlargelyresemblesaclosed-cycleunit. One option of such solutions implies the increase in pressureof allfluidcomponentspriortotheirsupplyingtothecombustionchamberintheliquidphasebypump equipment. SuchOCCGTUs, in which the pressure of fluidsis increasedin the liquid phase,withoutcompressors,are calledcompressor-less[13].

Thecyclesofcompressor-lessOCCGTUshaveseveralconsiderable advantages that serve as prerequisites for their extensive usein the near future.The possibilityofmosteffectively sequesteringcarbondioxide is certain to be the main factor that will facilitate theimplementation ofcompressor-lesscycles. Hazardousemissionswillbealmostexcluded, what will make it possible to remove CO_2andH_2Ocombustionproductsfrom the cyclein theliquidstate. The water is of rather high quality to be used withminimumwatertreatment invarioustechnologies or feed theheatingnetworks. Carbondioxidefromthecompressor-lessOCCGTUis brought out in a form, the most convenientfor transportation, includingtransportation by pipelines,duetoextremelylowviscosityofCO_2 [14].Compressor-lesscyclesofferquite as well prospectsofreaching the electric energy production efficiency factoras thebestmodernCCGTUs[13].When heatalong with electricity are produced, not onlyallheatbythelowheatvalueoffuel, but a substantial portion of vaporisation heatofwater, formedasaresultofcombustion,are used here[15].

Compressor-lesscyclesbelong to the category of semi-closed. Retaining the major advantage ofopencycles (intra-cyclecombustionand, thus, fewexergylosseswhen supplying heat from a hot sourcethrough the heat-exchange surface), they have virtually all advantages of closed cycles,with the possibility to efficiently controlthepowerunitcapacityas one of them [16]. Maintainingprincipalthermodynamicparameters (expansion ratein the turbine, temperatures of hot and cold sources) andchangingpressureinthecombustionchamber, throughchangingtheworking fluidrate, theOCCGTUcapacitychangeswithalmostnochangesinthethermodynamiccycleefficiency factor.

Sincecompressor-lessOCCGTUhasnoaircompressor (exclusive of means to produce oxygen, incaseofusingairseparationunit (ASU)), and fuel and oxygen can be used in the liquid form, a cycle with high initial pressure, hence, withhighspecific capacities of turbineswill be implemented.Such an opportunity will enable a substantial reduction in the OCCGTUweights and dimensions, and a decrease incapitalexpendituresfortheoverallconstructionoftheentirepowerstation.

Animportantadvantageofcompressor-lessthermodynamiccyclesalso involves a possibility of independently controlling the production of thermal and electric energyin a wide range.The compressor-lessOCCGTU, efficiently operated in summer,inwinterperiodcanmeet all demand for heat during the coldest dayswithnoadditionalpeakingboilerplants. AsopposedtoclassicCCGTUs, compressor-lessOCCGTUincogenerationmodepereachkWof electric capacity can produce 4 kWof thermal capacity. It will allow Russia to discardadditionalpeakingboilerplants, what will reduce capital expenditures forCHPPconstruction and decreaseoperatingexpenses, includingtheexpensestocaptureCO_2beyondboilers.

TheOCCGTUefficiencywithallowanceforthecostsincurred onoxygenproductionishigh, andthepriceofgeneratedelectricenergydoes not exceed its cost at the power stations with classic CCGTUs [17, 18]. Andthe initialstateofallcomponentsofworkingfluid in the liquid phase will enable short-term accumulation of their reserve and distribution of energy expenditures for their production and usesoastosmoothdailyloadcurvesofoutsideenergyconsumers [19].

The problem raised in the article about optimising the thermodynamiccycleanddesignlayout ofelectricpowerstation, for eco-friendly purposes, isdirectlyrelatedtothelocationofitsoperation.TheCCGTUs, availableonthemarket, areusuallyequippedwithgasturbineengines(GTE), initially designed to operatein the middle latitudes, at thecompressor-inlet air temperature of 288 Кor 300 К.When CCGTU operatesinotherclimaticconditions, theGTEparameters become non-optimal,evenwith the overall growth in its and the entire CCGTUefficiency factor,whenambient air temperature decreases. Here, ifthe isotherms of meanannualtemperatureinRussiaare analysed (Fig.1), the vastness can be noted of the territory with temperatureconditions,that differ, today and in theforeseeable future (Fig.2).Previously, the constructorsoftheLNG-plantoftheNovatekCompanyinYamalresponded to this peculiarity and developed their own project of liquefying natural gas, named“ArcticCascade”, which takesthespecificsoflocalcoldclimateinto account [20-26].

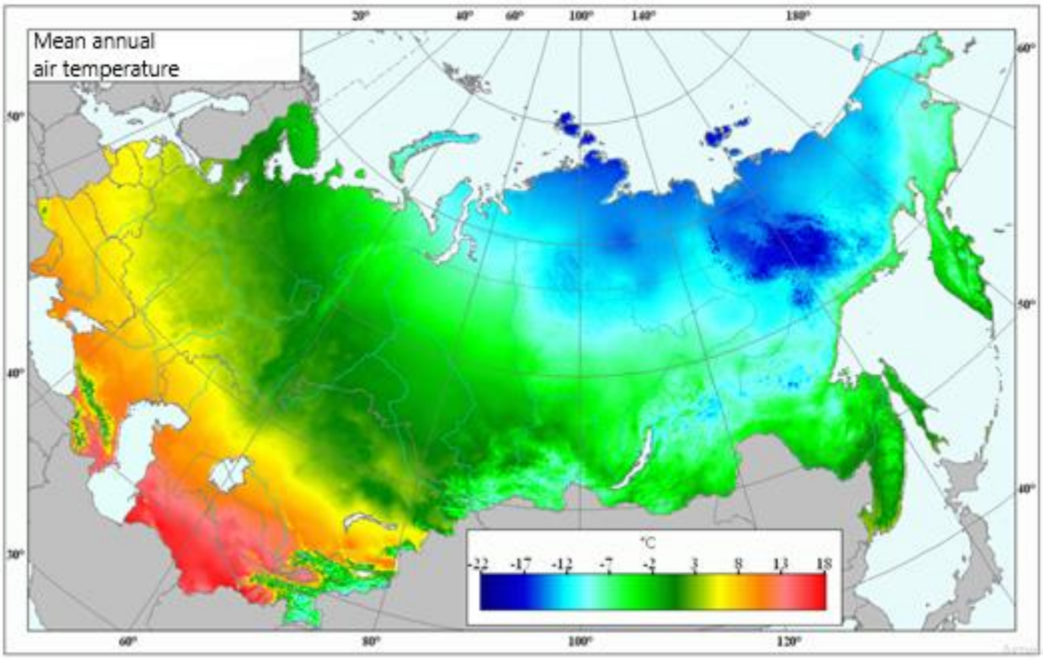

Fig. 1. Mean annual air temperature in the CIS territory [20]

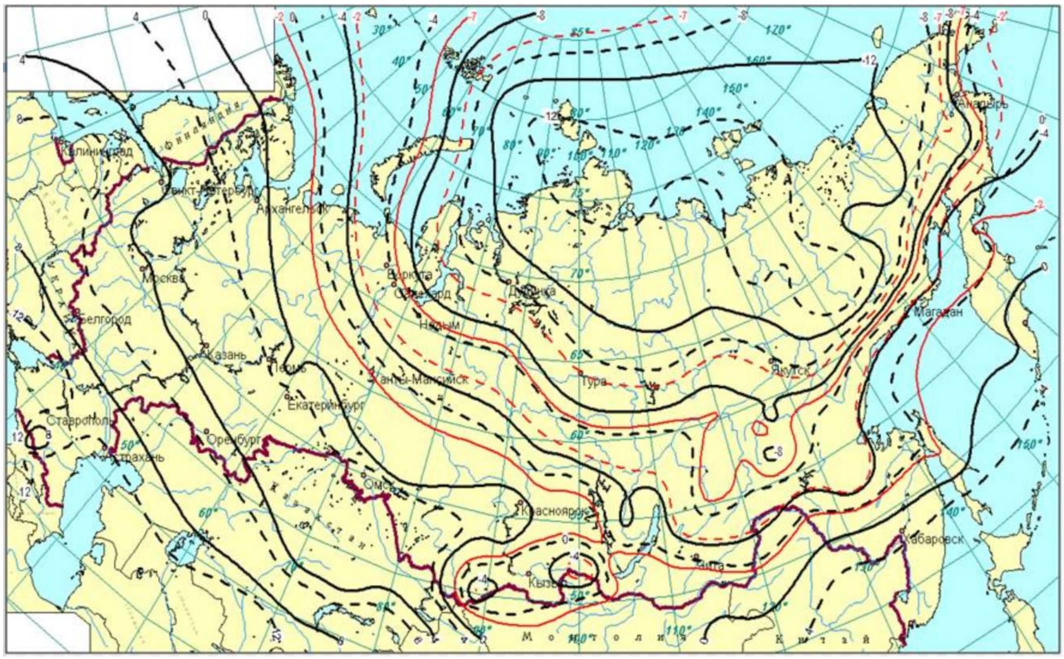

Fig. 2. Forecasted displaced mean annual isothermsby the mid-21stcentury (dashedlines)[21]

Inasimilarmanner,inthethermodynamiccycleofthecompressor-lessOCCGTUproject, takingintoconsiderationareducedtemperatureofthecoldsource – theambientenvironment,a ratherconsiderableincrement in the efficiency can be achieved and not only due to cold deficiency reduction inASUandwhen liquefyingCO_2 [27]. Thus, hightemperature of water condensation in the compressor-lessOCCGTUcycle and low temperature of cold source constitute optimal conditions for usingOrganic Rankine Cycle (ORC). In this case, using ORCprovides a substantial increment:about 5 absolutepercentofthecompressor-lessOCCGTUefficiencyfactor.

3. Compressor-less combined cycle gas turbine description

Figure 3 presentsoneofpossible diagrams of such abinaryplant.Mainelementsoftheplantareshowninthefigureaspositions 1-30, the directions of fluids movements are indicated. Suchplantoperatesaccordingtothefollowingalgorithm.

Carbon-containingfuel, forexample, naturalgas, burnt in the mixture of oxygen, water vapour, andcarbondioxide, issuppliedtothecombustionchamber (position 1, fromthispointon: Fig.3).Oxygentherewithcanbesuppliedfromanyknown source of oxygen, for instance, can be produced by ASU, incorporated in thepower-producingunitand receiving theelectricityneeded from it.

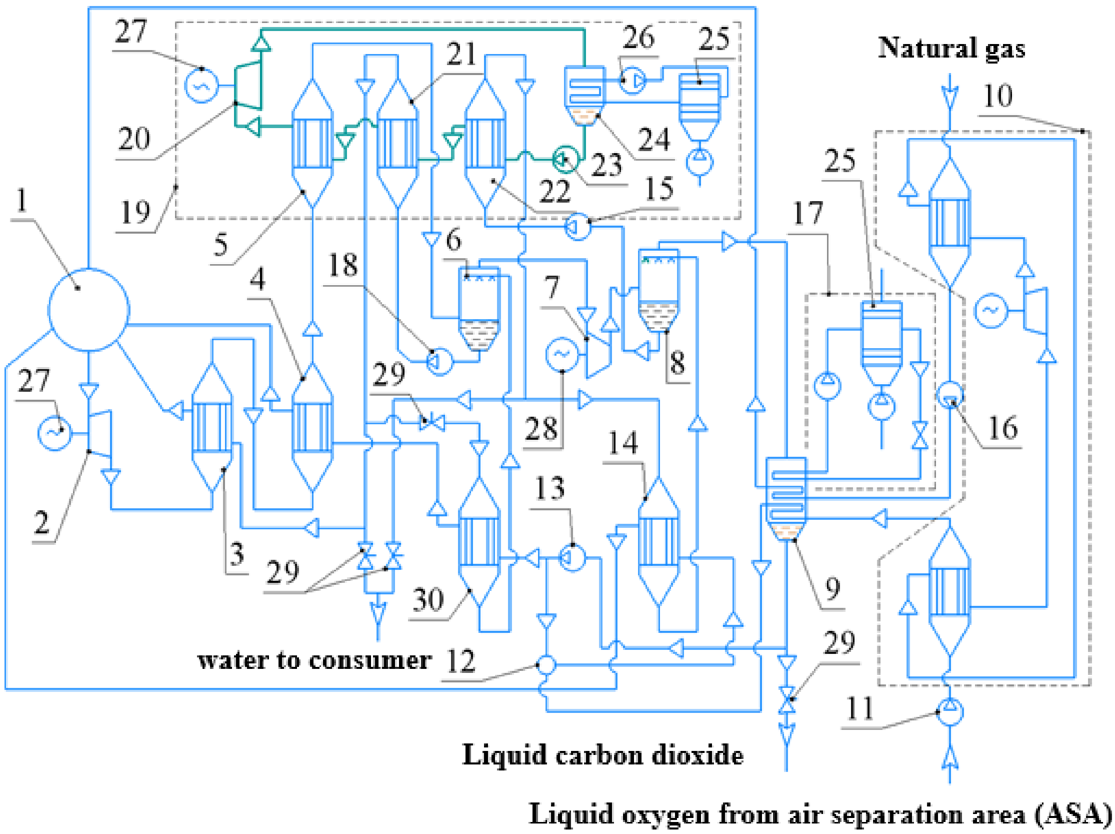

Fig.3. Processflowdiagramofcompressor-lessOCCGTunitwith ORC [28]

1-combustion chamber;2- combined cycle gas turbine;3-firstcooler of waste gases;4-secondcooler of waste gases;5-organicsteam superheater;6-firstcontact cooler of waste gases;7-compressor; 8-secondcontact cooler of waste gases,heat exchanger of carbon dioxide cycle heater(of the first cooler of waste gases); 9- carbon dioxide condenser, heat exchanger of oxygen cycle heater, heat exchanger of natural gas cycle heater; 10- natural gas liquefaction unit;11-oxygen control pump;12-mixing device;13-carbon-dioxide control pump;14-heat exchanger of carbon dioxide and oxygen mixture cycle heater–cooler ofthe secondcontact coolerwatercircuit; 15-circulation pump ofthe secondcontact coolerwatercircuit;16-fuel control pump; 17-unit of the heat pump for discharging heat energyto ambient environment; 18-water control pump; 19-ORC steam-turbine unit; 20-ORC turbine;21-ORC evaporator–water cooler unit of the first contact cooler of waste gases;22-ORCpreheater– cooler of the secondcontact coolerwatercircuit; 23-ORCfeed pump;24-ORC condenser;25-cooling tower; 26-circulation pump;27-turbogenerator; 28-actuator;29-adjustable gates; 30-heat exchanger of carbon dioxide cycle heater.

Allactivegases, includingcarbon-containingfuel, arecompressedintheliquefied state using pumps, what decreases energy consumed to re-pumpingand reaching the required pressure.

Combustionproductsareexpandedincombinedcyclegasturbine (2) withbackpressuremuch higher than the atmospheric (about 0.9 MPa), andsequentially pass through the first (3), second (4) cooler of waste gasesandorganicsteamsuperheater(5) ofORCunit (19), where waste gases are cooled to the temperature of water condensation onset owing to cooling waste gases to the temperature of at least 420 К. Fromorganicsteamsuperheater (5) cooledwastegasesenterthefirstcontactcooler (6) of waste gases, in which waste gases are cooled to the temperature of at least 273 К, and water in waste gases is condensed. Compressor (7) supplies waste gases from the first contact cooler (6) to thesecondcontactcooler (8) under the pressureclose to 3.5 MPa, where they are cooled to the temperature close the temperature of carbondioxidecondensation onset. Withthat, inthesecondcontactcooler (8) condensation of thewater, remained in waste gases, is also in progress. Then, driedgasfromthesecondcontactcooler(8) enterscarbondioxidecondenser(9), where$CO_2$is condensed through cooling to the temperature of at least 273 Кat the gas pressure of somewhat lower than the specified 3.5 MPa. The temperature and pressureinthecarbondioxidecondenser(9) are determined by the need for reachingthemaximumdegreeofcarbondioxidecapturefromcombustion products without forming thesolid phase, providinga high efficiency factorofOCCGTU.

Watercontrolpump (18) sends condensedwaterfromthefirstcontactcooler (6) to combustion chamber (1) through ORC evaporator (21)and heat-exchangerof water cycle heater, located in the first cooler (3) of waste gases. Aportionofwaterthrough heat-exchangerofcarbondioxidecycleheater(30), is sent to the circuit of the first contact cooler (6)of waste gases. Inthiscase, water, passingthroughheatexchanger (30), is cooled to at least 273 К, excludingthe solid phase.Theremainingportionofwaterissenttoan outside consumer. Waterconsumptionforheat-exchanger(6)andoutside consumeris regulated by gates (29).

Condensedcarbondioxideispouredoutcarbondioxidecondenser(9)tobefurtherusedoutside the unit or to be stored; at that, a certain required portion of liquid $CO_2$is sent by carbon dioxide control pump (13) to combustion chamber (1) through mixing device (12) and heat-exchanger ofcycleheaterofcarbondioxideandoxygen, located in block (14) of cooling water of the second contact cooler (8) of waste gases. Control pump (13) sends anotherportionofcarbondioxideto combustion chamber (1) through carbondioxidecycle heater (30)and heat-exchanger ofcarbondioxidecycleheaterofthe second cooler (4) ofwastegases.

LiquidoxygenfromASUis first sent byoxygencontrolpump (11), that enablespressurised oxygen supply to combustion chamber (1),to natural gasliquefaction unit (10), where liquid oxygen is heated due to heat exchange withgaseouscarbon-containingfuel. Thenoxygenenterstheheat-exchangerofoxygencycleheater, placedintheCO_2condenser(9), afterwardsitissuppliedtothemixingdevice (12) for mixing with carbondioxide, wherefrom it enters combustion chamber (1) as per the above-described route.

Carbon-containinggaseousfuelat the expense ofheat exchange withliquidoxygenisliquefiedin liquefaction unit ofgaseouscarbon-containing fuel (10)through using intermediate heat carrier. Control pump (16) further sends the fuel to combustion chamber (1), through heat-exchanger ofcarbon-containingfuelcycle heater, locatedintheCO_2condenser(9).

Hence, wateriscondensedthroughpre-coolingofwastegasesandheattransferinheatexchangers (5, 21, 22) ofORCunit (19) to the low-boilingorganicfluid, whichcanbe heated to more than 435К temperature, withitsphase transition to condenser (24), through ambient cooling. Such a considerableheat drop onorganicturbine (20) considerably increases the electric energy generated byturbo-generators (27) ofOCCGTU.

A change in the balance of energy generated byORCturbine(20)atthe constantgastemperatureupstreamofcombinedcyclegasturbine (2) can therewith be enabled by changing the productivity of water and carbon dioxide control pumps (18 and 13). Inthiscase, toobtainmoreenergyfromORC, the productivity of watercontrol pump (18) is increased, and to have more electric energy from combinedcyclegasturbine(2) asrelated to theORC turbine (20) - theproductivityofcarbondioxidecontrolpump(13) is increasedwith simultaneously decreasing water supply to the combustion chamber (1). Thus, incombustionchamber (1) abalanceis maintained betweeninertconstituents, which are needed to keep the temperature in combustion chamber (1) within the specified limits. The same procedures take place in thecompressor-lessOCCGTUwithcogenerationcircuit (insteadofORC), while switching-overthe unit thermal generation.

Thedescribedalgorithmisnottheonly possible option. TheOCCGTUproject withORCwill comprise a major task of determining an algorithm for optimal regulation of theOCCGTUoperationwithmaximumefficiencyandprovision ofnecessarycapacity, with allowance for changes in ambient temperature, outside heat consumption, amount ofaccumulatedenergy. And heredifferentoptionsare possible forregulation,varying not only water and carbon dioxide consumptionin combustion chamber (controlpumps 18 and 13), but also operation modeofotherOCCGTUelements.

Carbondioxideiscondensed incondenser (9) due to:

- pre-coolingofwastegasesinthesecond contact cooler (8) to the temperature close to the temperature of carbondioxide condensation onset;

- cooling ofwastegasesincondenser (9)itself, owing to cycle heating ofoxygenandfuel;

- transfer of heatthroughcoolingtower (25) to ambient environment.

When theambientenvironmenttemperatureisincreased, a deficiency of cold may be seen. Therefore, Figure 3 presentsapotentialsolutiontothisproblemwiththeuseofheatpump (17).

4. Usingcompressor-lesscombinedcyclegasturbinein various energo-technological complexes

Cold deficiency forrecuperativecompressor-lessOCCGTUcan also be reduced employingliquefiednaturalgas(LNG), when it is directly applied as the unit fuel. Here, profitability of using compressor-lessOCCGTU,when upgradingcoalCHPPsinSiberiaandtheFarEast, should be noted. Nogaspipelinesandproximityofcoalmineshereisthemainreasonforusingcoalasa fuel forCHPPsin these Russian regions. LNGfromexistingandLNG-plantsunderconstruction intheFarEasttosuchpower stations can be delivered, similarly to coal, by railwayincryogenic tanks.Then, usingcompressor-lessOCCGTUinsteadofcoal-basedCCGTUsin this case solves both the problem ofsequesteringgreenhouse gasesfrompower-producingunitsandcogeneration boilers,and the problem of increasing theefficiencyofelectricgeneratingequipment.

Thefollowingshouldbesaidfurther to theLNG subject matter. Worldwide natural gas consumption increases, andaccordingtotheIAEforecasts, the Asia-Pacific Region, which will account for almost 60% of the total growth ingas consumptionby 2024,willdefineamajordemandinthenearest years[22, 26]. Andthoughourcountryiswillingtosellpipeline gas toboth China, themaingasconsumerintheAsia-PacificRegion,andEurope, the LNG production becomes of importance for Russia, due to a global trend towards the greater use of LNG.Hence,of note aregood prospects of employingOCCGTUintechnologicalcomplexesofdifferenttypes, includingthosecreatedforchemicalprocessingofgasandutilisationofcarbondioxide.Thus, integrationofOCCGTUwith the mentioned NovatekLNG-plantpromisesa cleaner production. Energy-related component in the“Arcticcascade” project is based on GTEwitha relativelylowefficiencyandexhaustgaseswithCO_2. The “Arcticcascade” project withcompressor-lessOCCGTU andintegrationofthepower-producingunitthermodynamiccyclewiththe LNG-plantprovide considerableeconomic and environmental benefits.Figure 4 presentstheflowdiagramofsuchenergo-technologicalcomplexforliquefyingandprocessing natural gas.

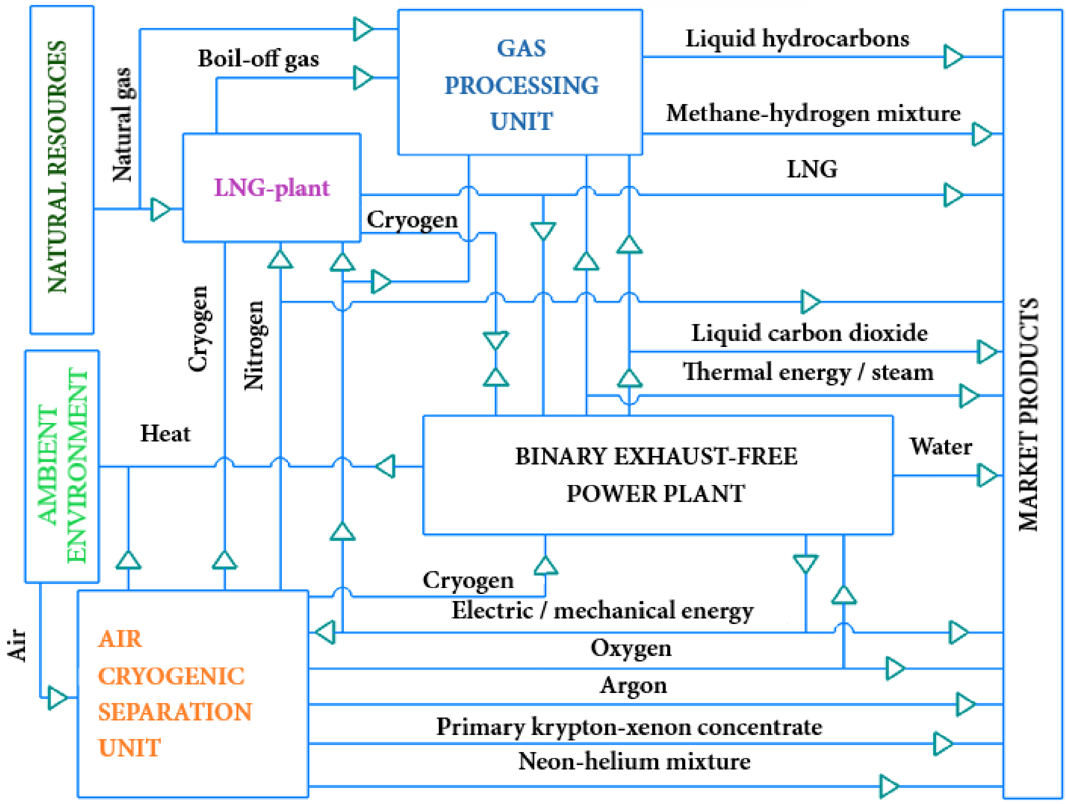

Fig. 4.Generalflow diagram ofenergo-technological complex for liquefying and processing natural gas [27]

Lowtemperatureofa coldsource – theambientenvironmentistheprerequisite for ahighefficiency of not onlyLNG-plant, but alsoOCCGTUwith an air cryogenic separation unit, and interrelation between them in exchanging fluids and energy sets a very high standard for this efficiency.Inthesymbiosis,energeticOCCGTU'sreceivingthefuelintheliquid state fromLNG-plantsaves energy for its liquefaction and excludes the respective device in the OCCGTUstructure (pos.10, Fig.3). Moreover, OCCGTUiscapableoftransmitting the required temperature and pressureto the unit of carbondioxidegasandsteam processing, and also oxygen to the ASU. ConsiderableASUenergyconsumptionisrelated to producing cold.TheautonomousASUtherewith uses mostly cryogenicpotential, and a major portion of "cold energy" is released to the ambient environment, whereas ASU in the consideredenergo-technologicalcomplex transfers along with nitrogen the "remnants of cold energy" to theLNG-plant, thus intensifying the specificsof the project, designed underlowmeanambienttemperatureconditions [24].

Potential production ofmanydiversemarketproducts also affects the growth in theefficiencyofintegrationproject of theLNG-plantwithOCCGTU. Use of energy, CO_2andsteamfromOCCGTUandboil-offgasfromLNG-plantcreates conditions for one more opportunity for such atechnologicalsymbiosis– productionofliquidhydrocarbonsandpotential enrichment of natural gas with hydrogen.

Fromenvironmentalperspective, theuseofa simple-cycleGTE[23, 24] asasourceofenergyfortheLNG-plantisfarfromoptimaloption, whatfollowsfromthefact that gas equivalent of energy spent to liquefy gas amounts to about 10% of liquefied gas [26]withtherespectiveCO_2emission.Insuchacase, usingOCCGTU, asasource of energy for theLNG-plantis justified.

In terms ofprofitability of employingcompressor-lessOCCGTUs, their use intheareasofundergroundcoalminingis of a similar nature. Here, mandatoryventilationofminesreleasesintotheatmosphereabundantmethane, whichgreenhouseeffectis 20 times greater than that ofcarbondioxide. Using compressor-lessOCCGTU enablessequestering of not onlyCO_2, but alsocoalmine methane from ventilation drifts of mines [29]. In solving the problem withcoalminemethane, it is possible to implement ahybridenergo-technologicalcomplex, when numerous ASUs with their energy from ventilation locationssupply a“base”compressor-lessOCCGTUwithoxygen. Hybridizationoptions of compressor-lessOCCGTUgo beyond it. Possibleoptionsofcombinedoperationofcompressor-lessOCCGTUwithrenewableenergysources (RES) andnuclearpowerplantsareunderconsideration, particularly,theuse of high-pressurewater electrolysers instead of ASUtosupplycompressor-lessOCCGTUswithoxygen[30].

Thearticleexaminesnoproblemsofusingandburyingcarbondioxide, towhichnumerousresearchanddevelopmentpublications[31-40]aredevoted, however, it should be noted that the use of compressor-lessOCCGTUcan significantly affect the solutions suggested in these areas. Thearticledescribestheadvantagesofusingcompressor-lessOCCGTUatdifferentenergo-technologicalfacilities,first and foremost, in terms of thecurrentvital task: reductioninman-madeemissionsofgreenhousegases. 180 countries, includingRussia, which had signedtheParisclimateagreement,are now faced with this task[41].

5. Conclusions

The main today’s task of science and developers is to createpriority projectsofpower-producingunits, which ensurerenewal ofkey funds ofelectric generatingenterprisesconsideringstrictrequirementsimposedongreenhousegasemissions.It is necessary to widen the searches forinnovativeconcepts of creatinghigh-efficiencypower-producingunitsto the systems, that take into account energy production preparation, and energy generation, potentialcombination with processcyclesandmanufacture ofchemical products, andutilisationofproductionwaste as well.

The consideredcompressor-lessCCGTunitis in compliance with the current requirements ofhigh-efficiencyeco-friendlypower-producingunits:

- generation ofelectricandthermalenergywiththe efficiencyfactornot lower thanthose of present-day CCGTUs,and also witha highCFU;
- noCO_2emissions;
- useofthisunitinvariousenergo-technologicalcomplexesprovides considerableeconomic and environmental benefits.

Acknowledgments

This work was prepared with the support of the RUDN University Program “5-100”.

References

[1] Global solar PV market set for spectacular growth over next 5 years. [Webresource: https://www.iea.org/newsroom/news/2019/october/global-solar-pv-market-set-for-spectacular-growth-over-next-5-years.html 21.10.2019].

[2] KondratyukB.V., GulidovR.V. Gas-turbine plants of SC Dal’energomashforUAL-7 (unified acid lines) process units// Khimicheskayatekhnika Journal No.4, 2017, pp. 20-22. /КондратюкВ.В., ГулидовР.В. ГазотурбинныеустановкиАО «Дальэнергомаш» длятехнологическихагрегатовУКЛ-7// журналХимическаятехника №4, 2017, стр. 20-22.

[3] Favorskiy O.N., Batenin V.M., Zeigarnik Y.A., Maslennikov V.M., Remizov A.N., Goryunov I.T., Makhan’kov A.K., Vasyutinskiy V.Y., Pischikov S.I., Sokolov Y.N., Yeliseev Y.S., Belyaev V.E., Kosoi A.S., Sinkevich M.V.Integratedcombined cycle gas turbine unit with steam injectionand heat pump plant (MES-60 CCGTU) for SC Mosenergo// TeploenergetikaJournalNo.9, 2001, pp. 50-58./ФаворскийО.Н., БатенинВ.М., ЗейгарникЮ.А., МасленниковВ.М., РемизовА.Н., ГорюновИ.Т., МаханьковА.К., ВасютинскийВ.Ю., ПищиковС.И., СоколовЮ.Н., ЕлисеевЮ.С., БеляевВ.Е., КосойА.С., СинкевичМ.В. Комплекснаяпарогазоваяустановкасвпрыскомпараитеплонасоснойустановкой (ПГУМЭС-60) дляАО «Мосэнерго» // ЖурналТеплоэнергетика №9, 2001 г., стр. 50-58.

[4] YeliseevY.S., BelyaevV.E., KosoiA.S., SinkevichM.V., SokolovY.N., ZeigarnikY.A., ShekhterY.L.MixingCCGTU: problemsandprospects// Journal “Gas-turbineTechnologies” No.2, 2006, pp.18-20 /ЕлисеевЮ.С., БеляевВ.Е., КосойА.С., СинкевичМ.В., СоколовЮ.Н., ЗейгарникЮ.А., ШехтерЮ.Л. ПГУсмешения: проблемыиперспективы // Журнал «Газотурбинныетехнологии» №2, 2006г., стр.18-20.

[5] KuznetsovS.K., BelyaevV.E., KosoiA.S., SinkevichM.V. CCGTunitoperationmode. RFPatentNo 2208684, publishedon 20.07.03, bulletinNo.20 /КузнецовС.К., БеляевВ.Е., КосойА.С., СинкевичМ.В. Способработыпарогазовойустановки. Патент РФ № 2208684, опубликовано 20.07.03, бюл. №20.

[6] BelyaevV.E., KosoiA.S., SinkevichM.V. Power-producing unit. RFPatentNo.2211342, publishedon 27.08.03, bulletinNo.24. /БеляевВ.Е., КосойА.С., СинкевичМ.В. Энергетическаяустановка. Патент РФ № 2211342, опубликовано 27.08.03, бюл. №24.

[7] BateninV.M., MaslennikovV.M., TolchinskiyL.S. Acombinedmethodforproducingelectricenergyandliquidsyntheticfuelusinggas-turbineandcombinedcyclegasturbineunits. RFPatentNo.2250872, publishedon 27.04.2005, bulletinNo.12 /Батенин В.М., Масленников В.М., Толчинский Л.С. Комбинированный способ производства электроэнергии и жидкого синтетического топлива с использованием газотурбинных и парогазовых установок. Патент РФ №2250872, опубликовано 27.04.2005, бюл. № 12.

[8] Atechnologyforproducingliquidcarbondioxide(CO_2) from flue gases of boiler house [Webresource: http://plamya-co2.ru/tech2.html, 30.09.2019.].

[9] Pre-Combustion Carbon Capture Research [Web resource: https://www.energy.gov/fe/science-innovation/carbon-capture-and-storage-research/carbon-capture-rd/pre-combustion-carbon, 30.09.2019.].

[10] Steam-generating anaerobic power-producing unitMESMA [Webresource: http://warfor.me/parogeneratornaya-anaerobnaya-energeticheskaya-ustanovka-mesma, 30.09.2019.].

[11] FanZheng, HackHorst, ZeltzerAndrew. Amethodforgeneratingenergyinpower-producingunitthroughburningcarbon-containingfuelinessentiallypureoxygen, power-producingunittogenerateenergythroughburningcarbon-containingfuelinessentiallypureoxygen; amethodformodifyingtheprocessofgeneratingenergythroughburningcarbon-containingfuelfrom burning fuel in the air to burning fuel in essentially pure oxygen. RFpatentNo.2433339, publishedon 10.11.2011, BulletinNo.31 /ФаньЧжень, ХэкХорст, ЗельцерЭндрю.Способ выработки энергии в энергетической установке посредством сжигания углеродсодержащего топлива в, по существу, чистом кислороде, энергетическая установка для выработки энергии посредством сжигания углеродсодержащего топлива в, по существу, чистом кислороде, способ модификации процесса выработки энергии посредством сжигания углеродсодержащего топлива от сжигания топлива в воздухе до сжигания топлива в, по существу, в чистом кислороде. Патент РФ № 2433339, опубликовано 10.11.2011, бюл. № 31.

[12] DavydovD. Theworld'sfirstAllamcycle-basedthermalpowerplantisputintooperation[Webresource: https://teknoblog.ru/2017/02/26/75321, 30.09.2019]./Давыдов Д. Запущена первая в мире ТЭС, работающая на основе Цикла Аллома [Интернет-ресурс: https://teknoblog.ru/2017/02/26/75321, 30.09.2019].

[13] KosoiA.S., ZeigarnikY.A., Popel’ O.S., SinkevichM.V., FilipovS.P., ShterenbergV.Y. Conceptualschemeofcombinedcyclegasturbineunitwithcompleteentrapmentofcarbondioxidefromcombustionproducts//TeploenergetikaJournalNo.9, 2018, pp.23-32. /Косой А.С., Зейгарник Ю.А., Попель О.С., Синкевич М.В., Филипов С.П., Штеренберг В.Я. Концептуальная схема парогазовой установки с полным улавливанием диоксида углерода из продуктов сгорания // Журнал Теплоэнергетика № 9, 2018 г., стр. 23-32.

[14] Viscosityofliquids.Machine-buildingEncyclopaediaXXL, p.16 [Webresource: https://mash-xxl.info/page/005186133094190224227236001247021020029164207184/ , 30.09.2019].

[15] KosoiA.S., KosoiA.A., SinkevichM.V., AntipovY.A. Method and plant for mechanical and thermal energy generation// RF Patent No.2665794, published on 04.09.2018, bull. No.25. /Косой А.С., Косой А.А., Синкевич М.В., Антипов Ю.А. Способ и установка для выработки механической и тепловой энергии. Патент РФ №2665794, опубликовано 04.09.2018, бюл. № 25.

[16] KosoiA.S., Popel’ O.S., SinkevichM.V. Methodandplantformechanicalandthermalenergygeneration //RFPatentNo.2651918, publishedon 24.04.2018, bull.12. /Косой А.С., Попель О.С., Синкевич М.В. Способ и установка для выработки механической и тепловой энергии. Патент РФ № 2651918, опубликовано 24.04.2018 г., бюл. 12.

[17] DavydovD. Theworld’sfirstAllamcycle-basedthermalpowerplantisputintooperationTEKNOBLOG 26.02.2017 [Webresource: https://teknoblog.ru/2017/02/26/75321, 30.09.2019.] /Д. Давыдов Запущена первая в мире ТЭС, работающая на основе Цикла Аллама ТЭКНОБЛОГ 26.02.2017 [Интернет-ресурс: https://teknoblog.ru/2017/02/26/75321, 30.09.2019.]

[18] A.Batyr’. Supercriticalapproach/ Howtoavoidenergy-consumingphase transformations// Energoznanie 13.03.2018. [WebResource:http://www.energovector.com/energoznanie-sverhkriticheskiy-podhod.html, 30.09.2019.] /А. Батырь Сверхкритический подход Как избежать энергозатратных фазовых превращений Энергознание 13.03.2018 [Интернет-ресурс: http://www.energovector.com/energoznanie-sverhkriticheskiy-podhod.html, 30.09.2019.]

[19] KosoiA.A. Methodtoregulateandplanttogeneratemechanicalandthermalenergy //RFpatentNo.2698865, publishedon 30.08.2019, BulletinNo.25 /КосойА.А. Способрегулированияиустановкадлявыработкимеханическойитепловойэнергии. Патент РФ № 2698865, опубликовано 30.08.2019, бюл. № 25.

[20] Agroecologicalatlas of Russia and bordering countries. Themapofmeanlong-term average annualairtemperature. [Webresource: http://www.agroatlas.ru/content/agroecology/climatic_maps/Temperature_avg/Temperature_avg/Temperature_avg_ru_big.gif, 30.09.2019.] /Агроэкологический атлас России и сопредельных стран. Карта средней среднемноголетней температуры воздуха за год. [Интернет-ресурс:

http://www.agroatlas.ru/content/agroecology/climatic_maps/Temperature_avg/Temperature_avg/Temperature_avg_ru_big.gif, 30.09.2019.]

[21] V.V. Klimenko, A.V. Klimenko. Global warming: an enemy or an ally? Presentation, slide 24, 2.06.2010. [Webresource: http://900igr.net/prezentacija/ekologija/globalnoe-poteplenie-vrag-ili-sojuznik-242228/izotermy-srednegodovykh-temperatur-4.html, 30.09.2019.] /В.В.Клименко, А.В.КлименкоГлобальноепотеплениеврагилисоюзник? Презентация, слайд 24, 2.06.2010г. [Интернет-ресурс: http://900igr.net/prezentacija/ekologija/globalnoe-poteplenie-vrag-ili-sojuznik-242228/izotermy-srednegodovykh-temperatur-4.html, 30.09.2019.]

[22] Gas 2019 Analysis and forecasts to 2024 [Web resource: https://www.iea.org/gas2019/ 30.11.2019.]

[23] MinigulovR.M., RudenkoS.V., VasinO.E., GritzishinD.N., SobolevE.I. Amethod for liquefying natural gasusinghigh-pressure cycle with ethane precooling and nitrogen supercooling"Arctic Cascade", and installation to implement it. RFPatentNo.2645185, publishedon 16.02.2018, BulletinNo.5. /МинигуловР.М., РуденкоС.В., ВасинО.Е., ГрицишинД.Н., СоболевЕ.И. Способсжиженияприродногогазапоциклувысокогодавленияспредохлаждениемэтаномипереохлаждениемазотом "АРКТИЧЕСКИЙКАСКАД" иустановкадляегоосуществления. Патент РФ № 2645185, опубликовано 16.02.2018, бюл. № 5.

[24] O.E. Vasin, R.M. Minigulov, V.V. Bodnaruk, E.R. Ibragimov, D.V. Pashinkin, V.I. SitasKinematicsofLNGplantsrefrigerantcompressors\\ Journal "Gas-turbineTechnologies", April-May (No.3) 2018, pp. 28-30. /О.Е.Васин, Р.М.Минигулов, В.В.Боднарук, Е.Р.Ибрагимов, Д.В.Пашинкин, В.И.Ситас Кинематические схемы компрессоров хладагента установок по производству СПГ \\ Журнал: «Газотурбинные технологии», апрель-май (№3) 2018, стр. 28-30.

[25] UpdatedGIS-packagesofthelatestgeologicalinformationasof01.01.2018 (GIS-atlas "NedraRossii") [Webresource: http://atlaspacket.vsegei.ru/#d13c969fec5749c511, 30.09.2019.] /Актуализированные ГИС-пакеты оперативной геологической информации по состоянию на 01.01.2018 (ГИС-Атлас «Недра России») [Webresource: http://atlaspacket.vsegei.ru/#d13c969fec5749c511, 30.09.2019.]

[26] Farruggio G., Bertelsen M. LNG'sboostforrenewables[Webresource: https://www.rystadenergy.com/newsevents/news/press-releases/lngs-boost-for-renewables/, 30.09.2019.].

[27] BorisovY.A., KosoiA.A., MaksimovA.L., NovikovV.A. Energotechnologicalcomplexfornatural gas processingandthecomplexoperationmode //RFPatentNo. 2739165, publishedon21.12.2020, bulletin 35. /БорисовЮ.А., КосойА.А., МаксимовА.Л., НовиковВ.А. ЭнерготехнологическийкомплекспереработкиприродногогазаиспособработыкомплексаПатентРФ №2739165, опубликовано 21.12.2020, бюл. № 35.

[28] KosoiA.A., SinkevichM.V. Plantforthermalandmechanicalenergygenerationandmethodforitsregulation //RFPatentNo.2723264, publishedon 09.06.2020, bulletinNo.16. /КосойА.А., СинкевичМ.В. Установкадлявыработкитепловойимеханическойэнергииислособеерегулирования.Патент РФ №2723264, опубликовано 09.06.2020, бюл. № 16.

[29]BorisovY.A., KosoiA.A., Popel' O.S. Energotechnologicalcomplexforgeneratingthermalandmechanicalenergyandthecomplexoperationmode //RFPatentNo. 2732530, publishedon 21.09.2020, bulletinNo.27. /Борисов Ю.А., Косой А.А., Попель О.С. Энерготехнологический комплекс для выработки тепловой и механической энергий и способ работы комплекса». Патент РФ №2732530, опубликовано 21.09.2020, бюл. № 27.

[30] Mefco2 project[Web resource: http://mefco2.eu/, accessed on 30.10.2020.].

[31] V.V. Nedolivko, G.O. Zasypalov, A.V. Vutolkina, P.A. Guschin, V.A. Vinokurov, L.A. Kulikov, S.V. Egazar'yantz, E.A. Karakhanov, A.L. Maksimov, A.P. Glotov. Carbon-dioxideconversion of methane (review)// Applied Chemistry Journal. 2020. V. 93. Issue 6, pp.763-785. /В.В. Недоливко, Г.О. Засыпалов, А.В. Вутолкина, П.А. Гущин, В.А. Винокуров, Л.А. Куликов, С.В. Егазарьянц, Э. А. Караханов, А. Л. Максимов, А. П. ГлотовУглекислотнаяконверсияметана (обзор)// Журналприкладнойхимии. 2020. Т. 93. Вып. 6, с. 763-785.

[32] KrylovO.V. Carbon-dioxideconversionofmethaneintosynthesis-gas //"Rossiyskiykhimicheskiyjurnal" Journal. 2000. V. 44. No.1. pp. 19-33. /Крылов О.В.Углекислотная конверсия метана в синтез-газ//Журнал: «Российский химический журнал». 2000. Т. 44. № 1. С. 19-33.

[33] GumerovF.M. Prospectsofusingcarbondioxidetoincreasereservoirrecoveryrate //"Gas Science Chronicle"/"Vestigazovoinauki" Scientific-technical digest. 2011. No.2 (7). pp. 93-109. /Гумеров Ф.М. Перспективы применения диоксида углерода для увеличения нефтеотдачи пластов//Научно-технический сборник Вести газовой науки. 2011. № 2 (7). с. 93-109.

[34] Novel carbon capture and utilization technologies Informs the European Commission Group of Chief Scientific Advisors Scientific Opinion No. 4/2018Web resource:https://www.sapea.info/wp-content/uploads/CCU-report-web-version.pdf, accessed on 30.01.2020.

[35] Carbondioxideisusedasan industrialreactivechemicalforthefirst time. Webresource: https://indicator.ru/news/2018/07/26/uglekislyj-gaz-v-promyshlennosti/, accessedon 30.01.2020. /Углекислый газ впервые используют как реагент в промышленности Интернет ресурс: https://indicator.ru/news/2018/07/26/uglekislyj-gaz-v-promyshlennosti/, обращение 30.01.2020.

[36] Chemists from Germany learnt to transform air into aprotein-based "manna".Webresource: https://ria.ru/science/20180726/1525382314.html, accessedon 30.01.2020. /Химики из Германии

научились превращать воздух в белковую "манну"Интернет ресурс: https://ria.ru/science/20180726/1525382314.html , обращение 30.01.2020.

[37] The research conducted in Norway proves that the use of “captured CO2” increases yield in greenhouses. Webresource: https://www.fruit-inform.com/ru/technology/grow/182072#.XkPmyWZ7l9A, accessedon 12.02.2020 /Проведенное в Норвегии исследование доказывает, что применение «отловленного CO2» повышает урожай в теплицах Интернет ресурс: https://www.fruit-inform.com/ru/technology/grow/182072#.XkPmyWZ7l9A, обращение 12.02.2020.

[38] Brent D.F. Improved integrated chemical process //RF Patent No.2504426, published on 10.10.2012, bull. No.28 /Брент Д.Ф. Усовершенствованный интегрированный химический процесс, патент РФ №2504426, опубликовано 10.10.2012, бюл. № 28.

[39] SlastunovS.V., KarkashadzeG.G. Environmentallyfriendlytechnologyforburyinggreenhousegasesincoalseams// “Mininginfo-analyticbulletin”/ ”Gorniyinformatsionno-analiticheskiybyulleten” Journal 2012, No.12. pp.318-322 /Сластунов С.В., Каркашадзе Г.Г. Экологически чистая технология захоронения парниковых газов в угольных пластах// журнал «Горный информационно-аналитический бюллетень» 2012, № 12. с. 318-322

[40] KolikovK.S., PuchkovL.A., SlastunovS.V., KarkashadzeG.G. Methodforextractingmethanefromthe coalseam. RFPatentNo. 2323327, publishedon 27.04.2008 Bull. No.12 /КоликовК.С., ПучковЛ.А., СластуновС.В.,КаркашадзеГ.Г. Способизвлеченияметанаизугольногопласта. Патент РФ № 2323327, опубликован 27.04.2008 Бюл. № 12

[41] TheDecreeofthePresidentoftheRussianFederation “Ongreenhousegasemissionreduction” datedNovember 4, 2020 No.666 /УказПрезидентаРФ «Осокращениивыбросовпарниковыхгазов» от 4 ноября 2020г. №666.