TOMSK POLYTECHNIC UNIVERSITY
ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ

Министерство науки и высшего образования Российской Федерации
федеральное государственное автономное
образовательное учреждение высшего образования
«Национальный исследовательский Томский политехнический университет» (ТПУ)

Школа Инженерная школа ядерных технологий
Направление подготовки 14.03.02 Ядерные физика и технологии
Отделение школы (НОЦ) Отделение ядерно-топливного цикла

БАКАЛАВРСКАЯ РАБОТА

Тема работы
Анализ сорбционной емкости по водороду таблеток из технического углерода

УДК 661.66-026.772:66.081:661.96

Студент

Группа	ФИО	Подпись	Дата
0А8Д	Хусаинов Темирлан Кайратович		

Руководитель ВКР

Должность	ФИО	Ученая степень, звание	Подпись	Дата
Профессор ОЯТЦ ИЯТШ	Видяев Дмитрий Геннадьевич	д.т.н.		

Консультант

Должность	ФИО	Ученая степень, звание	Подпись	Дата
Старший преподаватель ОЯТЦ ИЯТШ	Побережников Андрей Дмитриевич			

КОНСУЛЬТАНТЫ ПО РАЗДЕЛАМ:

По разделу «Финансовый менеджмент, ресурсоэффективность и ресурсосбережение»

Должность	ФИО	Ученая степень, звание	Подпись	Дата
Доцент ОСГН ШИП	Якимова Т.Б.	к.э.н.		

По разделу «Социальная ответственность»

Должность	ФИО	Ученая степень, звание	Подпись	Дата
Доцент ОЯТЦ ИЯТШ	Передерин Ю.В.	к.т.н.		

ДОПУСТИТЬ К ЗАЩИТЕ:

Руководитель ООП	ФИО	Ученая степень, звание	Подпись	Дата
Ядерные физика и технологии	Бычков П.Н.	к.т.н.		

Томск – 2022 г.

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ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ

Министерство науки и высшего образования Российской Федерации
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образовательное учреждение высшего образования
«Национальный исследовательский Томский политехнический университет» (ТПУ)

School of Nuclear Science & Engineering
Field of training (speciality): 14.03.02 Nuclear Science and Technology
Nuclear Fuel Cycle Division

BACHELOR THESIS

Тема работы
Analysis of the hydrogen sorption capacity of carbon black tablets

UDC 661.66-026.772:66.081:661.96

Student

Group	Full name	Signature	Date
0A8D	Khussainov Temirlan Kairatovich		

Scientific supervisor

Position	Full name	Academic degree, academic rank	Signature	Date
Professor of NFCD	Vidyaev D.G.	D.Sc. in Technology		

Consultunt

Position	Full name	Academic degree, academic rank	Signature	Date
Senior lecturer of NFCD	Poberezhnikov A.D.			

ADVISERS:

Section «Financial Management, Resource Efficiency and Resource Saving»

Position	Full name	Academic degree, academic rank	Signature	Date
Associate professor	Yakimova T.B.	PhD		

Section «Social Responsibility»

Position	Full name	Academic degree, academic rank	Signature	Date
Associate professor	Perederin Y.V.	PhD		

ADMITTED TO DEFENCE:

Programme Director	Full nmae	Academic degree, academic rank	Signature	Date
Nuclear Science and Technology	Bychkov P.N.	PhD		

Tomsk – 2022 y.

ПЛАНИРУЕМЫЕ РЕЗУЛЬТАТЫ ОБУЧЕНИЯ

Код компетенции	Результаты освоения ООП (компетенции)
Универсальные	
УК(У)-1	Способен осуществлять поиск, критический анализ и синтез информации, применять системный подход для решения поставленных задач
УК(У)-2	Способен определять круг задач в рамках поставленной цели и выбирать оптимальные способы их решения, исходя из действующих правовых норм, имеющихся ресурсов и ограничений
УК(У)-3	Способен осуществлять социальное взаимодействие и реализовывать свою роль в команде
УК(У)-4	Способен осуществлять деловую коммуникацию в устной и письменной формах на государственном языке Российской Федерации и иностранном(-ых) языке(-ах)
УК(У)-5	Способен воспринимать межкультурное разнообразие общества в социально-историческом, этическом и философском контекстах
УК(У)-6	Способен управлять своим временем, выстраивать и реализовывать траекторию саморазвития на основе принципов образования в течение всей жизни
УК(У)-7	Способен поддерживать должный уровень физической подготовленности для обеспечения полноценной социальной и профессиональной деятельности
УК(У)-8	Способен создавать и поддерживать безопасные условия жизнедеятельности, в том числе при возникновении чрезвычайных ситуаций
УК(У)-9	Способен проявлять предприимчивость в профессиональной деятельности, в т.ч. в рамках разработки коммерчески перспективного продукта на основе научно-технической идеи
Общепрофессиональные	
ОПК(У)-1	Способен использовать базовые знания естественнонаучных дисциплин в профессиональной деятельности, применять методы математического анализа и моделирования, теоретического и экспериментального исследования
ОПК(У)-2	Способен осуществлять поиск, хранение, обработку и анализ информации из различных источников и баз данных, предоставлять ее в требуемом формате с использованием информационных, компьютерных и сетевых технологий
ОПК(У)-3	Способен использовать в профессиональной деятельности современные информационные системы, анализировать возникающие при этом опасности и угрозы, соблюдать основные требования информационной безопасности, в том числе защиты государственной тайны
Профессиональные компетенции	
ПК(У)-1	Способен использовать научно-техническую информацию, отечественный и зарубежный опыт по тематике исследования, современные компьютерные технологии и информационные ресурсы в своей предметной области
ПК(У)-2	Способен проводить математическое моделирование процессов и объектов атомной отрасли с использованием стандартных методов и компьютерных кодов для проектирования и анализа
ПК(У)-3	Готов к проведению физических экспериментов по заданной методике, составлению описания проводимых исследований и анализу полученных экспериментальных данных
ПК(У)-4	Способен использовать технические средства для измерения основных параметров объектов исследования
ПК(У)-5	Готов к составлению отчета по выполненному заданию, к участию во внедрении результатов исследований и разработок
ПК(У)-6	Способен использовать информационные технологии при разработке новых установок, материалов и приборов, к сбору и анализу исходных данных для проектирования объектов атомной отрасли
ПК(У)-7	Способен к расчету и проектированию деталей и узлов приборов и установок в соответствии с техническим заданием
ПК(У)-8	Готов к разработке проектной и рабочей технической документации, оформлению законченных проектно-конструкторских работ
ПК(У)-9	Способен к контролю соответствия разрабатываемых проектов и технической документации стандартам, техническим условиям, требованиям безопасности и другим нормативным документам
ПК(У)-10	Готов к проведению предварительного технико-экономического обоснования проектных решений при разработке установок и приборов
ПК(У)-11	Способен к контролю за соблюдением технологической дисциплины и обслуживанию технологического оборудования
ПК(У)-12	Готов к эксплуатации современного физического оборудования, приборов и технологий
ПК(У)-13	Способен к оценке ядерной и радиационной безопасности, к оценке воздействия на окружающую среду, к контролю за соблюдением экологической безопасности, техники безопасности, норм и правил производственной санитарии, пожарной, радиационной и ядерной безопасности, норм охраны труда

ПК(У)-14	Готов разрабатывать способы применения ядерно-энергетических, плазменных, лазерных, сверхвысокочастотных и мощных импульсных установок, электронных, нейтронных и протонных пучков, методов экспериментальной физики в решении технических, технологических и медицинских проблем
ПК(У)-15	Способен к составлению технической документации (графиков работ, инструкций, планов, смет, заявок на материалы, оборудование), а также установленной отчетности по утвержденным формам

LEARNING OUTCOMES

Competencies code	Competence name
Universal competences	
UC(U)-1	Ability to make critical analysis of problem-based situations using the systems analysis approach, and generate decisions and action plans.
UC(U)-2	Ability to determine the range of tasks within the framework of the goal and choose the best ways to solve them, based on current legal regulations, available resources and restrictions
UC(U)-3	Ability to carry out social interaction and realize their role in the team
UC(U)-4	Ability to carry out business communication in oral and written forms in the state language of the Russian Federation and foreign language(s)
UC(U)-5	Ability to perceive the intercultural diversity of society in the socio-historical, ethical and philosophical contexts
UC(U)-6	Ability to manage his time, build and implement a trajectory of self-development based on the principles of education throughout life
UC(U)-7	Ability to maintain the proper level of physical fitness to ensure full-fledged social and professional activities
UC(U)-8	Ability to create and maintain safe living conditions, including in case of emergencies
UC(U)-9	Ability to show entrepreneurship in professional activities, incl. as part of the development of a commercially promising product based on a scientific and technical idea
General professional competences	
GPC(U)-1	Ability to use basic knowledge of natural sciences in professional activities, apply methods of mathematical analysis and modeling, theoretical and experimental research
GPC(U)-2	Ability to search, store, process and analyze information from various sources and databases, provide it in the required format using information, computer and network technologies
GPC(U)-3	Ability to use modern information systems in professional activities, analyze the dangers and threats arising from this, comply with the basic requirements of information security, including the protection of state secrets
Professional competences	
PC(U)-1	Ability to use scientific and technical information, domestic and foreign experience on research topics, modern computer technologies and information resources in their subject area
PC(U)-2	Ability to carry out mathematical modeling of processes and objects of the nuclear industry using standard methods and computer codes for design and analysis
PC(U)-3	Ready for conducting physical experiments according to a given methodology, compiling a description of ongoing research and analyzing the experimental data obtained
PC(U)-4	Ability to use technical means to measure the main parameters of research objects
PC(U)-5	Ready to draw up a report on the completed task, to participate in the implementation of research and development results
PC(U)-6	Ability to use information technologies in the development of new installations, materials and devices, to the collection and analysis of initial data for the design of nuclear industry facilities
PC(U)-7	Ability to calculate and design parts and assemblies of devices and installations in accordance with the terms of reference
PC(U)-8	Ready for the development of design and working technical documentation, registration of completed design work
PC(U)-9	Способен к контролю соответствия разрабатываемых проектов и технической документации стандартам, техническим условиям, требованиям безопасности и другим нормативным документам
PC(U)-10	Ready to conduct a preliminary feasibility study of design solutions in the development of installations and devices
PC(U)-11	Capable of monitoring the observance of technological discipline and maintenance of technological equipment
PC(U)-12	Ready for operation of modern physical equipment, instruments and technologies
PC(U)-13	Ability to assess nuclear and radiation safety, to assess the impact on the environment, to monitor compliance with environmental safety, safety regulations, norms and rules of industrial sanitation, fire, radiation and nuclear safety, labor protection standards
PC(U)-14	Ready to develop ways to use nuclear power, plasma, laser, microwave and high-power pulse installations, electron, neutron and proton beams, methods of experimental physics in solving technical, technological and medical problems
PC(U)-15	Ability to draw up technical documentation (work schedules, instructions, plans, estimates, applications for materials, equipment), as well as established reporting in approved forms

TOMSK POLYTECHNIC UNIVERSITY | ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ

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федеральное государственное автономное
образовательное учреждение высшего образования
«Национальный исследовательский Томский политехнический университет» (ТПУ)

Школа Инженерная школа ядерных технологий
Направление подготовки 14.03.02 Ядерные физика и технологии
Отделение школы (НОЦ) Отделение ядерно-топливного цикла

УТВЕРЖДАЮ:
Руководитель ООП
________ ____________ Бычков П.Н.
(Подпись) (Дата) (Ф.И.О.)

ЗАДАНИЕ
на выполнение выпускной квалификационной работы

В форме:

Бакалаврской работы

(бакалаврской работы, дипломного проекта/работы, магистерской диссертации)

Студенту:

Группа	**ФИО**
0А8Д	Хусаинову Темирлану Кайратовичу

Тема работы:

Анализ сорбционной емкости по водороду таблеток из технического углерода	
Утверждена приказом директора (дата, номер)	01.02.2022 г., № 32-52/с

Срок сдачи студентом выполненной работы:	31.05.2022

ТЕХНИЧЕСКОЕ ЗАДАНИЕ:

Исходные данные к работе	– сведения из литературных источников; – вид исследуемых материалов; – параметры проведения процессов фабрикации технического углерода.

Перечень подлежащих исследованию, проектированию и разработке вопросов	– провести обзор и сравнение наиболее безопасных и рациональных методов хранения водорода, а также вариантов использования углерода в качестве сорбента; – разработать методику оценки сорбционной емкости углеродных таблеток; – определить предельную теоретическую сорбционную емкость таблеток по водороду.
Перечень графического материала	– презентация

Консультанты по разделам выпускной квалификационной работы
(с указанием разделов)

Раздел	**Консультант**
Литературный обзор;	Побережников А.Д.
Финансовый менеджмент, ресурсоэффективность и энергосбережение	Якимова Т.Б.
Социальная ответственность	Передерин Ю.В.

Дата выдачи задания на выполнение выпускной квалификационной работы по линейному графику	01.02.2022

Задание выдал руководитель / консультант:

Должность	**ФИО**	**Ученая степень, звание**	**Подпись**	**Дата**
Профессор ОЯТЦ ИЯТШ	Видяев Д.Г.	д.т.н.		
Старший преподаватель ОЯТЦ ИЯТШ	Побережников А.Д.			

Задание принял к исполнению студент:

Группа	**ФИО**	**Подпись**	**Дата**
0А8Д	Хусаинов Темирлан Кайратович		

TOMSK POLYTECHNIC UNIVERSITY ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ

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образовательное учреждение высшего образования
«Национальный исследовательский Томский политехнический университет» (ТПУ)

School of Nuclear Science & Engineering
Field of training (speciality): 14.03.02 Nuclear Science and Technology
Nuclear Fuel Cycle Division

APPROVED BY:
Program Director
________ ___________ Bychkov P.N.
(Signature) (Date) (Full name)

ASSIGNMENT
for the Graduation Thesis completion

In the form:

Bachelor Thesis

Student:

Group	Full name
0A8D	Khussainov Temirlan Kairatovich

Topic of the research work:

Analysis of the hydrogen sorption capacity of carbon black tablets	
Approved by the order of the Director of School of Nuclear Science & Engineering (date, number):	01.02.2022 y., № 32-52/c

Deadline for completion of Bachelor Thesis:	31.05.2022

TERMS OF REFERENCE:

Initial date for research work:	– information from literary sources; – type of materials under study; – parameters of carbon black fabrication processes.

List of the issues to be investigated, designed and developed	– review and compare the safest and most rational methods of hydrogen storage, as well as options for using carbon as a sorbent; – to develop a methodology for assessing the sorption capacity of carbon tablets; – to determine the maximum theoretical sorption capacity of tablets for hydrogen.
List of graphic material	– presentation

Advisors to the sections of the Bachelor Thesis
(with indications of sections)

Section	Advisor
Literature Review	Poberezhnikov A.D.
Financial Management, Resource Efficiency and Resource Saving	Yakimova T.B.
Social Responsibility	Perederin Y.V.

Date of issuance of the assignment for Bachelor Thesis completion according to the schedule	

Assignment issued by a scientific supervisor / advisor:

Position	Full name	Academic degree, academic rank	Signature	Date
Professor of NFCD	Vidyaev D.G.	D.Sc. in Technology		
Senior lecturer of NFCD	Poberezhnikov A.D.			

Assignment accepted for execution by a student:

Group	Full name	Signature	Date
0A8D	Khussainov Temirlan Kairatovich		

ЗАДАНИЕ ДЛЯ РАЗДЕЛА
«ФИНАНСОВЫЙ МЕНЕДЖМЕНТ, РЕСУРСОЭФФЕКТИВНОСТЬ И РЕСУРСОСБЕРЕЖЕНИЕ»

Студенту:

Группа	ФИО
0А8Д	Хусаинову Темирлану Кайратовичу

Школа	ИЯТШ	**Отделение школы (НОЦ)**	ОЯТЦ
Уровень образования	Бакалавриат	**Направление/специальность**	Ядерные физика и технологии

Исходные данные к разделу «Финансовый менеджмент, ресурсоэффективность и ресурсосбережение»:	
1. *Стоимость ресурсов научного исследования (НИ): материально-технических, энергетических, финансовых, информационных и человеческих*	*Стоимость материальных ресурсов в соответствии с рыночными ценами г. Томска. Тарифные ставки исполнителей в соответствии со штатным расписанием НИ ТПУ.*
2. *Нормы и нормативы расходования ресурсов*	*Коэффициенты для расчета заработной платы.*
3. *Используемая система налогообложения, ставки налогов, отчислений, дисконтирования и кредитования*	*Коэффициент отчислений во внебюджетные фонды – 30,2 %.*
Перечень вопросов, подлежащих исследованию, проектированию и разработке:	
1. *Оценка коммерческого потенциала, перспективности и альтернатив проведения НИ с позиции ресурсоэффективности и ресурсосбережения*	*Анализ потенциальных потребителей результатов исследования. Исследование конкурентных технических решений. Проведение SWOT-анализа*
2. *Планирование и формирование бюджета научных исследований*	*Определение трудоемкости работ. Разработка графика проведения научного исследования. Формирование бюджета затрат научно-исследовательского проекта*
3. *Определение ресурсной (ресурсосберегающей), финансовой, бюджетной, социальной и экономической эффективности исследования*	*Проведение оценки сравнительной эффективности проекта.*
Перечень графического материала *(с точным указанием обязательных чертежей)*:	
1. *Оценка конкурентоспособности технических решений* 2. *Матрица SWOT* 3. *График проведения и бюджет НИ* 4. *Оценка ресурсной, финансовой и экономической эффективности НИ*	

Дата выдачи задания для раздела по линейному графику	

Задание выдал консультант:

Должность	ФИО	Ученая степень, звание	Подпись	Дата
Доцент ОСГН	Якимова Т.Б.	канд. экон. наук		

Задание принял к исполнению студент:

Группа	ФИО	Подпись	Дата
0А8Д	Хусаинов Т.К.		

ASSIGNMENT FOR SECTION
«FINANCIAL MANAGEMENT, RESOURCE EFFICIENCY AND RESOURCE SAVING»

Student:

Group	Full name
0A8D	Khussainov Temirlan Kairatovich

School	Nuclear Science and Engineering	**Division**	Nuclear Fuel Cycle
Degree	Bachelor	**Field of training**	Nuclear physics and technologies

Initial data to the section «Financial management, resource efficiency and resource saving»:	
1. The cost of scientific research resources (SR): logistical, energy, financial, informational and human	*The cost of material resources in accordance with the market prices of the city of Tomsk. Tariff rates of performers in accordance with the staffing table of NR TPU.*
2. Norms and standards of resource spending	*Coefficients for payroll calculation.*
3. Taxation system used, tax rates, deductions, discounting and lending	*The coefficient of deductions to off-budget funds is 30.2 %.*
The list of subjects to study, design and develop:	
1. Evaluation of the commercial potential, prospects and alternatives for conducting scientific research from the standpoint of resource efficiency and resource saving	*Analysis of potential consumers of the research results. Research of competitive technical solutions. Conducting a SWOT analysis*
2. Planning and budgeting for scientific research	*Determination of labor intensity of work. Development of a schedule for conducting a scientific study. Formation of the budget for the costs of a research project*
3. Determination of resource (resource-saving), financial, budgetary, social and economic efficiency of the study	*Conducting an assessment of the comparative effectiveness of the project.*
A list of a graphic material:	
1. Assessment of the competitiveness of technical solutions *2. SWOT matrix* *3. Schedule and budget for NI* *4. Assessment of resource, financial and economic efficiency of research*	

Date of issue of the task for the section according to the schedule	

Assignment issued by an advisor:

Position	Full name	Academic degree, academic rank	Signature	Date
Associate professor	Yakimova T.B.	PhD		

Assignment accepted for execution by a student:

Group	Full name	Signature	Date
0A8D	Khussainov T.K.		

ЗАДАНИЕ ДЛЯ РАЗДЕЛА
«СОЦИАЛЬНАЯ ОТВЕТСТВЕННОСТЬ»

Студенту:

Группа	ФИО
0А8Д	Хусаинову Темирлану Кайратовичу

Школа	**ИЯТШ**	**Отделение (НОЦ)**	**ОЯТЦ**
Уровень образования	Бакалавр	**Направление/специальность**	Ядерные физика и технологии

Тема ВКР:

Анализ сорбционной емкости по водороду таблеток из технического углерода	
Исходные данные к разделу «Социальная ответственность»:	
1. *Описание рабочего места (рабочей зоны, технологического процесса, механического оборудования) на предмет возникновения*	Вредных проявлений факторов производственной среды: микроклимат, шум, вибрация, освещение, электромагнитные поля и ионизирующее излучение от ПЭВМ; опасных проявлений факторов производственной среды: электрического тока, пожарная и взрывная безопасность.
2. *Перечень законодательных и нормативных документов по теме*	Требования охраны труда при работе на ПЭВМ; электробезопасность; пожаровзрывобезопасность.
Перечень вопросов, подлежащих исследованию, проектированию и разработке:	
1. *Анализ выявленных вредных факторов проектируемой производственной среды в следующей последовательности*	Действие фактора на организм человека; приведение допустимых норм с необходимой размерностью (со ссылкой на соответствующий нормативно-технический документ); предлагаемые средства защиты (сначала коллективной защиты, затем – индивидуальные защиты).
2. *Анализ выявленных опасных факторов проектируемой произведённой среды в следующей последовательности*	Электробезопасность (причины, средства защиты); пожаровзрывобезопасность (причины, профилактические мероприятия, первичные средства пожаротушения).

Дата выдачи задания для раздела по линейному графику	

Задание выдал консультант:

Должность	ФИО	Ученая степень, звание	Подпись	Дата
Доцент ОЯТЦ ИЯТШ	Передерин Ю. В.	к.т.н.		

Задание принял к исполнению студент:

Группа	ФИО	Подпись	Дата
0А8Д	Хусаинов Т.К.		

ASSIGNMENT FOR SECTION «SOCIAL RESPONSIBILITY»

Student:

Group	Full name
0A8D	Khussainov T.K.

School	Nuclear Science and Engineering	**Division**	**Nuclear Fuel Cycle**
Degree	Bachelor	**Field of training**	Nuclear physics and technologies

Topic of the research work:

Анализ сорбционной емкости по водороду таблеток из технического углерода	
Initial data to the section «Social responsibility»:	
1. *Description of the workplace (work area, process, mechanical equipment) for the occurrence*	Harmful manifestations of industrial environment factors: microclimate, noise, vibration, lighting, electromagnetic fields and ionizing radiation from a PC; dangerous manifestations of industrial environment factors: electric current, fire and explosion safety.
2. *List of legislative and regulatory documents on the topic*	Labor protection requirements when working on a PC; electrical safety; fire and explosion safety.
List of issues to be researched, designed and developed::	
1. *Analysis of the identified harmful factors of the designed production environment in the following sequence*	The effect of the factor on the human body; reduction of permissible norms with the required dimension (with reference to the relevant regulatory and technical document); proposed means of protection (first collective protection, then individual protection).
2. *Analysis of identified hazardous factors of the designed manufactured environment in the following sequence*	Electrical safety (reasons, means of protection); fire and explosion safety (causes, preventive measures, primary fire extinguishing agents).

Date of issue of the task for the section according to the schedule	

Assignment issued by an advisor:

Position	Full name	Academic degree, academic rank	Signature	Date
Associate professor	Perederin Y.V	PhD		

Assignment accepted for execution by a student:

Group	Full name	Signature	Date
0A8D	Khussainov T.K.		

TOMSK POLYTECHNIC UNIVERSITY — ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ

Министерство науки и высшего образования Российской Федерации
федеральное государственное автономное
образовательное учреждение высшего образования
«Национальный исследовательский Томский политехнический университет» (ТПУ)

Школа Инженерная школа ядерных технологий
Направление подготовки (специальность) 14.03.02. Ядерные физика и технологии
Уровень образования высшее
Отделение школы (НОЦ) Отделение ядерно-топливного цикла
Период выполнения ____________ (весенний семестр 2021 /2022 учебного года)

Форма представления работы:

Бакалаврская работа

(бакалаврская работа, дипломный проект/работа, магистерская диссертация)

КАЛЕНДАРНЫЙ РЕЙТИНГ-ПЛАН
выполнения выпускной квалификационной работы

Срок сдачи студентом выполненной работы:	31.05.2022

Дата контроля	Название раздела (модуля) / вид работы (исследования)	Максимальный балл раздела (модуля)
05.02.2022	*Постановка цели и задач*	*5*
07.02.2022	*Составление и утверждение ТЗ*	*5*
30.02.2022	*Подбор и изучение материалов по тематике*	*10*
01.03.2022	*Разработка календарного плана*	*5*
06.03.2022	*Обсуждение литературы*	*10*
12.04.2022	*Разработка программы*	*15*
17.04.2022	*Исследование спектров*	*10*
24.05.2022	*Верификация программы*	*20*
31.05.2022	*Оформление расчетно-пояснительной записки*	*20*

СОСТАВИЛ:
Руководитель ВКР

Должность	ФИО	Ученая степень, звание	Подпись	Дата
Профессор ОЯТЦ ИЯТШ	Видяев Д.Г.	д.т.н.		

СОГЛАСОВАНО:
Руководитель ООП

Должность	ФИО	Ученая степень, звание	Подпись	Дата
Доцент ОЯТЦ	Бычков П.Н.	к.т.н.		

Министерство науки и высшего образования Российской Федерации
федеральное государственное автономное
образовательное учреждение высшего образования
«Национальный исследовательский Томский политехнический университет» (ТПУ)

School of Nuclear Science & Engineering
Field of training (speciality): 14.03.02 Nuclear Science and Technology
Nuclear Fuel Cycle Division
Period of completion (spring semester 2021/2022 academic year)

Form of presenting the work:

Bachelor Thesis

SCHEDULED ASSESSMENT CALENDAR
for the Bachelor Thesis completion

Deadline for completion of Bachelor Thesis:	31.05.2022

Assessment date	Title of section (module) / type of work (research)	Maximum score for the section (module)
05.02.2022	*Setting goals and objectives*	*5*
07.02.2022	*Drafting and approval of TT*	*5*
30.02.2022	*Selection and study of materials on the subject*	*10*
01.03.2022	*Development of the calendar plan*	*5*
06.03.2022	*Literature discussion*	*10*
12.04.2022	*Program development*	*15*
17.04.2022	*Spectra study*	*10*
24.05.2022	*Program verification*	*20*
31.05.2022	*Registration of a settlement and explanatory note*	*20*

COMPILED BY:
Scientific supervisor:

Должность	Full name	Academic degree, academic rank	Signature	Date
Professor of NFCD	Vidyaev D.G.	D.Sc. in Technology		

APPROVED BY:
Program Director

Position	Full name	Academic degree, academic rank	Signature	Date
Associate professor	Bychkov P.N.	PhD		

Abstract

Final qualifying work contains 86 p., 7 figures, 35 tables, 50 sources of literature, 1 application.

Key words: carbon black, hydrogen, sorption, press powder, sintering, tableting.

The object of the study is the sorption capacity of carbon black tablets.

Purpose of the work: to study the sorption capacity of carbon-based tablets for hydrogen sorption.

An analysis of the hydrogen sorption capacity of tablets based on carbon black was carried out as a result of the study and limiting capacities of tablets were determined. The limiting sorption capacity of carbon-based tablets was found, depending on the composition, pressing pressure and the presence of sintering. It is shown that with increasing pressure, the free volume in the tablets decreases, and, as a result, the sorption capacity decreases. It was also determined that for pure carbon tablets, sintering increases the pore volume by an average of 29%, and for tablets with the addition of sodium stearate, it decreases by 27%.

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Introduction

In the modern world, great demands are placed on the environmental friendliness of energy systems in order to reduce greenhouse gas emissions and thereby counter the problem of climate change on the planet. In particular, the transition of internal combustion engines to a new type of fuel is considered, hydrogen is proposed as one of the options, since as a result of combustion in pure oxygen, the products will be water and thermal energy. Hydrogen also has a number of advantages: low molecular weight, high energy content and unlimited reserves, since it can be extracted from water, and the specific energy of hydrogen combustion is 3 times higher than that of gasoline. For hydrogen energy, one of the main problems is the safe storage and transportation of hydrogen.

A possible solution to the problem could be the use of carbon sorbents as hydrogen storage materials. Since they can have a sufficiently developed sorption surface and relatively low cost. One form of carbon suitable for industrial use as a sorbent is carbon black.Purpose of the work is to study the sorption capacity of carbon-based tablets for hydrogen sorption.

In accordance with the goal, the following series of tasks was drawn up:

1. Review and compare the safest and most rational methods of hydrogen storage, as well as options for using carbon as a sorbent;
2. To develop a methodology for assessing the sorption capacity of carbon tablets;
3. Determine the limiting theoretical sorption capacity of tablets for hydrogen.

1 Literature review

1.1 Hydrogen as an alternative energy source

1.1.1 Basic hydrogen properties

Under normal conditions, hydrogen is a tasteless, colorless, odorless gas. When cooled to a liquid state, hydrogen occupies one seven hundredth of the volume of the gaseous state. Since hydrogen is very reactive, it is practically absent in the free state. Most often, found in combination with other elements, for example, in water with oxygen. Because liquid hydrogen releases a large amount of energy when burned, it used as a source of rocket fuel, in which high-energy content and low molecular weight are important factors. Water and high-temperature heat will be the main combustion products of hydrogen in pure oxygen [1].

It can concluded that when using hydrogen, no harmful substances formed, and the water cycle in nature is not disturbed. Hydrogen is one of the most abundant elements on Earth. There are 17 hydrogen atoms for every 100 atoms. If we take into account that the mass fraction of hydrogen in water is 11.19%, and water on the planet is more than $1.5 \cdot 10^{18}$ m^3, it becomes clear that the raw material base for hydrogen production on Earth is a huge amount. In addition, if we take into account the fact that hydrogen does not form pollutants during combustion, then we can talk about the prospects of hydrogen technologies. The concept of hydrogen technology implies a set of industrial methods and means for producing, transporting and storing hydrogen, as well as technologies for its safe use based on inexhaustible sources of raw materials and energy.

1.1.2 Hydrogen storage

The storage of hydrogen as an energy carrier is a complex issue that affects the production, delivery and end use of it. It is a key technology for the hydrogen economic development. As well as in a solid medium, Hydrogen can be stored in a gaseous state (compressed gas), liquid (20 K or –253 °C), and also hydrocarbons. It is not difficult to find out that the first two methods are established technologies with some limitations

[2], the most important of them is energy-intensive nature. The solid-state hydrogen storage, still in its unprecedented infancy seems to be an alternative that is possible. Moreover, this is due to its increased safety and volumetric energy density. In addition, when this solution is chosen, losses in weight efficiency, thermal management and scaling will have to be taken into account. Innovative scientific work is currently underway, which will help to overcome the limitations of existing storage hydrogen technology and develop effective solutions in terms of performance or energy.

Storage in gaseous form

It is currently one of the simplest, most widespread, and most efficient storage technologies. Hydrogen under high pressure is stored in thick-walled tanks (mostly cylindrical or quasi-conformal) made of high-strength materials for durability. The design of the storage tank based on classical deterministic engineering approaches not optimized yet: the tanks are actually large, inefficient use of material and rather poor life expectancy of pressure vessels [3, 4].

As part of The EU Integrated Hydrogen Project, the European project is leading the development of global regulatory standards for gas and liquid gas storage tanks, compressed gas and hydrocarbon storage tanks can be classified into four different groups:

1. full-metal cylinder;
2. load-bearing metal case wrapped with resin-impregnated continuous thread;
3. metal non-load-bearing axial liner wrapped with resin-impregnated continuous thread;
4. non-metal non-load-bearing axial liner wrapped with resin-impregnated continuous thread.

Storage in liquid forms or media

The hydrogen in liquid form has a much higher energy density than in gaseous form, making it an attractive storage medium. Liquid hydrogen and related technology have already been used in space (Space Shuttle Ariane) as well as in military aircraft. In the field of land transport, a number of vehicles have been prepared and tested to run on hydrogen in newly designed tanks with evaporative losses of less than 1.5 wt.% per day for hydrogen-based systems that are equipped with hydrogen gasoline at low temperatures from 1.5 wt.% per day. At the same time, automated filling stations with liquid hydrogen have also been made [5].

This hydrogen storage system is well-efficient but has some drawbacks. The energy required to liquidify the gas, as well as its pressure and control of temperature for preventing any overpressure in order not to have an overpressure risk. It also needs cryogenic devices and suffers from hydrogen losses due to evaporation from small containers (they have the large surface volume ratio than large containers, hence more hydrolysis). [7]. The continuously vaporized hydrogen can be catalytically burned by air in the overpressure protection system of an overpressure protected box, or even collected again in metal hydride.

Storage in metal hydrides

In the metal hydrides, based on metal-alloys, they act as an absorber of gaseous hydrogen. After an chemical reaction under the pressure of hydrogen, solid metal-containing gases and heat were produced. This is due to the fact that after reacting under hydrogen pressure, solid substances of carbon with metal are made and heat was releasen. Conversely, the release of hydrogen is due to materials exposed to heat, such as in order to reduce pressure and heating tanks. Hydrogen is first absorbed on the surface and then dissociates into tightly-bound individual hydrogen atoms. To optimize both the weight of the system and temperature at which hydrogen can be reduced, metals were alloyed to improve both the weight of the system and its weight. If it is necessary to use hydrogen, then the hydride was released from the hydride at certain temperatures and pressures. This process can be repeated many times, without leaving storage capacity [7].

Storage in carbon materials

On solid surfaces, hydrogen is adsorbed and reversibly accumulated by the use of pressure and temperature. Hydrogen can be adsorbed and reversibly accumulated as a result of physical adsorption (van der Waals forces) or chemisorption (as in metal hydrides). At the same time, high specific area materials such as nanostructured carbon and carbon Nanotubes can be used as substrates for physical adsorption. High specific material properties are possible substrates for physical adsorption. A comparison of storage capabilities, curved carbon nanotubes and graphite is more effective than high surface area graphite (25% more at low temperatures). In terms of storage capacity, curved structures such as carbon nanotubes seem to be more efficient in terms of storage.

They are inherently interacting with the hydrogen atom, and thereby have a high attractiveness forces acting compared to open structures with flat surfaces [4, 8]. When temperature increases, this effect weakens.

If you look at the latest results of studies that have been published in recent years, you can see conflicting data on the reversible storage and reversible collection of hydrogen in carbon nanotubes. For the most part, this is due to the insufficient characterization of carbon material used. In 1998 extraordinary hydrogen storage capacities were found, an order of magnitude greater than any previously recorded. This capacitance values are questionable and should be viewed with some skepticism, as they cannot be reproducible. Hydrogenic storage properties in nanotubes remain unclear. Hydrogen storage properties in nanotubes are not yet fully understood. Although there is still scientific interest in single-walled nanotubes, which can be seen as promising medium for the safe storage of hydrogen, there is still scientific interest. Researchers are convinced that they should conduct careful and systematic research, focusing on development to improve sorption properties. As well as characterization of materials in order for better performance with this material is required by most people who have studied them. With such procedures, as ball milling and pre-treatment, it is possible to increase the number of defects such as carbon breaks in carbon bonds, can lead to highly defective structure in that hydro chemisorbed and readily released.

Specific indicators of the main methods of hydrogen storage presented in Table 1.2.

Table 1.1 – Specific indicators of hydrogen storage methods [9]

Storage method	Specific energy consumption, kWh/kg H_2	Specific storage volume, dm^3/kg H_2	Specific mass of storage, kg/kg H_2
Hydrogen gas at low pressure	0,39	1020	–
Hydrogen gas at high pressure	0,93	81	16,0
Hydrogen in hydrides	1,16	22	76,9
Liquid hydrogen	10,50	14	7,0
Cryogenic adsorption	3,20	59	20,0

The advantages and disadvantages of the main hydrogen storage methods shown in Table 1.2.

Table 1.2 – Assessment of the main methods of hydrogen storage [10]

Storage method	Advantages	Disadvantages
Liquid hydrogen (T = 300 K, p ≤ 20 MPa)	The technology is well developed and available, relatively low cost	Low volume capacity (about 7.7 kg/m^3 at 10 MPa). The density of stored energy at high pressures (up to 70 MPa) is comparable to liquid hydrogen, but the storage technology at such high pressures has not been fully developed
Liquid hydrogen (T = 20.4 K)	Technology available, high density (71 kg/m^3)	High energy consumption for liquefaction, loss of hydrogen, for evaporation, the need for super-insulation, as a result, high cost

Table 1.2 – Continuation

Cryogenic adsorption (T = 155 K)	The technology is simple and well developed	Low volume capacity (0.5– 20 kg/m^3). The need for cooling and compression
Hydrides of metals, alloys, intermetallic compounds and composites	Convenience and safety of storage in the solid phase (in a bound state); a number of technologies are quite well developed	Insufficient capacity, need for heating, degradation over time, relatively high cost
Carbon nanostructures: nanotubes, fullerenes	Technologies in the future can provide a high density of hydrogen storage (30–100 kg/m^3)	The production of carbon structures is not sufficiently developed, the results of hydrogen retention are irreproducible

A promising method is the sorption of hydrogen by porous materials, in particular, carbon-based.

1.2 Carbon sorbents

1.2.1 Carbon and its variants uses for sorption.

The properties of substances determined by their chemical composition, the structure of the crystal lattice and the structure of the molecules that make up the substance.

Carbon has several structural modifications:

– Fullerenes;

– Nanotubes;
– Graphite nanofiber;
– Technical carbon.

The adsorption energy of technical carbon at various degrees of coverage is the smallest and is -4.25 eV, while the average energy of hydrogen adsorption by fullerenes and nanotubes -2.63 eV and -2.41eV respectively. This suggests that, other things being equal, the process of hydrogen sorption will be more stable when technical carbon is used.

Technical carbon refers to a class of industrial carbon products where the carbon is in a form not found in naturally occurring materials. It is a polydisperse powdery material, black in color, formed in the gas phase during thermal or thermal-oxidative decomposition of carbon-containing substances, mainly hydrocarbons.

The use of carbon in powders, as well as its disadvantages: smaller than compacted forms area of contact with gas and the density of the sorbent; low density of the material; high hydrostatic pressure due to an accidental contamination by finely dispersed materials. The impact on the operation of the system due to its contamination with finely dispersed substances is not eliminatable after saturating with gas [11].

1.3 Porosity of materials

1.3.1 Characteristics of the porous structure

In fact, as they name says, porous materials contain many Pores. As their name suggests, such material has much more than one pore. The main porous framework of the solid is continuous, and the liquid part forms the liquid phase. Porous solids consist of a continuous solid phase, which forms the main porous framework, and a liquid one, which forms pores in the solid. In the latter, it is possible to consist of gas if there is a gaseous medium in the pore, or of liquid if there is a liquid medium in the pore.

According to different porous materials, the number of pores will vary. In the amount of pores, they can be divided into low, medium or high porosity materials depending on the number of Porous Materials. According to the general behavior of porous materials, low to medium porosity have closed pores that behave like an impurity phase. With high-porous material, for porous materials with high Porosity, there are two cases depending on the different structure of the pore and continuous solid state. The first case, a continuous rigid body forms a two-dimensional array of polygons; the pores are isolated in space and create polygonal columns. It is usually triangular, quadrangular or hexagonal. The cross-sectional shape of the pore can be triangular, quadrangular, quadrangular or hexagonal. In this structure, the structure is similar to a hexagonal honeycomb cell, and such two-dimensional porous materials are called honeycomb materials. By name of the lotus-type porous materials, or honeycomb type Porous Materials with directional peres [12], such as lotus-typeporous materials, have similar structure to honeycomb materials. But in contrast for honeycomb material products, round or Elliptical pores are used on them, so that it is difficult to pass through them and result in less distribution uniformity and density of the array. There are two cases in the second case: solid body is a three-dimensional mesh structure, and such porous materials can be classified as three-dimensional mesh foam.

This materials have interconnecting pores with open cell structure that are typical for such materials. In the fourth case, a solid body showed an internal wall structure of pores with shapes of polyhedral or pentagonal form and such three-dimensional porous materials can be called foamed materials in the form of bubbles. The cell wall can separate many isolated pores or cells, forming an closed cell foam similar to the bubbles. In addition, the cell wall can be composed of open-celled bubble like polymer foam. Literature, 3D mesh foams are referred to as "open cell" and open cell and microbubble like foams are described as semi open cell. In the literature, 3D mesh foams are also classified as "closed cell".

As well as artificial and natural, porous solids include two types of porous bodies (ie, natural and artificial). [13] Natural porous solids are found in the natural world [13], such as bones that support the bodies and limbs of animals and humans, plant leaves, wood, coral pumice and lava. The liquid phase that is contained in the pores of plant leaves and living tree trunks, as well as gas inside artificial porous materials, always consists of liquid, while gas mainly used inside artificial Porous

Materials. In the Artificial porous materials, artificial material can be divided into metals, porous polymers and foam polymers.

The total (true) porosity is the entire volume of pores in a given volume of material. Total porosity P_t, %, calculated according to the formula:

$$P_t = \left(1 - \frac{\rho_0}{\rho}\right) \cdot 100 \qquad (1.1)$$

The open porosity of a material is the volume of those pores that communicate with the external environment. Their volume can be measured by the water saturation of the material. Open porosity, $P_{op,}$ % , calculated according to the formula:

$$P_{op} = \left(\frac{m_1 - m_2}{V}\right) \cdot \left(\frac{1}{\rho_w}\right) \cdot 100 \qquad (1.2)$$

where m_1 and m_2 are the mass of the sample, respectively, in the saturated and dry state; V is the volume of material; ρ_w is the density of water.

Closed porosity P_{cl} found by the difference between total and open porosity:

$$P_{cl} = P_t - P_{op} \qquad (1.3)$$

The value of porosity greatly affects the strength of the material.

The strength value also depends on the pore size: it increases with their decrease. The strength of fine-porous materials, as well as materials with closed porosity, is higher than the strength of large-porous and open-porous materials [14].

1.3.2 Methods for studying the porous structure

The distribution of pore volume of a porous solid as a function of pore size is becoming increasingly important for understanding the chemical and physical behavior of porous materials. To understand and predict the macro behavior and properties of an engineered material, it is often necessary to examine the microstructure of the material. For many porous engineering materials, including carbon, voids greatly affect the mechanical properties. Thus, the analysis of the microstructure of these materials must include the determination of the pore size distribution in order to predict accurately their macrobehavior.

The method of capillary condensation also often referred to as gas or vapor absorption. For this method, the total pore volume and pore size distribution are determined from gas adsorption isotherms. The pore volume is the volume of condensed adsorbate at saturated vapor pressure. When the pressure reduced, the adsorbate first evaporates from the larger capillaries, as dictated by the Kelvin equation.

The method of mercury porosmetry proposed by Vosborn (1921), later developed by Ritter and Drake (1945), and further developed by Winslow and Shapiro (1959). Since most materials not wetted by mercury, a minimum pressure p is required to force the mercury through the constriction. The pressure required to penetrate a circular pore of radius r determined by the Young and Laplace equation and can be written as:

$$p=\frac{2\gamma \cdot \cos\theta}{r}, \tag{1.4}$$

where γ – surface tension of mercury and θ – angle of contact of the meniscus with the walls of the capillary.

The pore volume distribution is determined by measuring the volume of mercury infiltrated into the sample when the pressure is increased. The measured pressure values converted to pore radii using Equation 1.4.

Recently, two theories have been put forward to explain the hysteresis and mercury trapping after extrusion. Hill (1960) states that penetration progresses in the axial direction while extrusion progresses in the radial direction. Considering this assumption correct, Hill shows that the extrusion pressure should be equal to half the penetration pressure for a cylindrical pore. Hill also provides experimental evidence to support this theory. This theory also predicts that if the neck radius is less than half the body radius for a system of essentially cylindrical pores, then mercury trapping will occur in the pore bodies [15].

The method of saturation (or impregnation) is a method used to weigh a clean, dry sample until it was completely saturated with the wetting liquid. In the past, toluene or dichloromethane were used for most of the time, but in recent times it has been common to saturate sample with a synthetic brine that has a cationic and anionic composition. As it is determined, the weight of a saturated sample is calculated after removing excess brine from the surface. This is the bulk volume of an sample in its form, such as one that has a shape or not. It is determined by geometrical methods with help of caliper to find out how much material is used for preparing it. In addition, it is necessary to know the density of the saturating liquid or determine it by weighing an existing volume of liquid.

Similar to the saturation method, in which the dry weight is determined and then the sample saturated with a wetting liquid of density that has known density, the buoyancy method also works similarly to the saturation technique. It is then determined the total volume of a sample. But in this approach, the saturated sample was suspended under a bath of liquid with similar substances to obtain its weighed weight. A cradle used to suspend the sample is also required so that a real weight of the sample and its cradle suspended in liquid can be taken into account in porosity calculations.

In the world, optical petrology is one of the simplest, most reproducible and reproducible methods for evaluating a pore system. It is necessary to better identify cracks and pores. The sample impregnated with one of two type of epoxy, Normal Blue or Rhodamine-B for UV fluorescence, to highlight the pore system by illuminating the pore system. In the end, the section is viewed under plane-polarized or cross polarizing light to assess two-dimensional crosssections and evaluate the bulk mineral composition. It is possible to make important observations regarding structure of material by calculating points or examining pictures from mineralogy: diagenesis, pore system, and the quality of the sample reservoir by counting points in order to find out about its structure and shape through counting points or analysis of imagery of mineralogy, formation process, diagenesis. Despite the huge number of information available, despite the large amount of information available, the actual three-dimensional grain ratio and details of the intergranular pore structure have always been not provided [16].

It is possible to scientifically study open macroporosity, which is the basis of research. The method for this is visual-optical and light microscopy, capillary thermoporemetry liquid and gas volumeometry hydrostatic flow of fluids, hydrostatic fluency of liquids filling pores with a liquid, hydrostatic interaction of liquids, reference porosimetry. In order to achieve the desired results, it is practically expedient to combine the methods of microscopy, filling pores with liquid, and reference porosimetry.

1.3.3 Features and parameters of the porous structure of carbon-based sorbents

Highly porous carbon sorbents are solid substances that have a developed specific surface area and are capable of selectively absorbing various substances from liquid and gaseous media [17]. In addition, carbon sorbents are high molecular weight materials in terms of chemical composition [18].

Since carbon sorbents typically have a complex porous structure, they have different types of pores, but there is also a predominance of a particular type of pores. Therefore, they belong to inhomogeneous porous materials. Depending on the size of the pores and their distribution over the volume, the area of use of a particular sorbent selected.

Carbon sorbents have a developed system of micropores (0.6–0.7 nm) and supermicropores (0.7 < r < 1.5 nm), which distinguishes them favorably from other highly porous materials and is one of the main structural features. Since for the adsorption of gases and in most cases for the adsorption of liquids, supermicropores and micropores play the main role. The pore volume of carbon microporous sorbents ranges from 0.2 to 0.6 cm^3/g. Adsorption forces act throughout the entire volume of active pores, as a result of which the adsorption of substances is reduced to the complete volumetric filling of the entire pore space with them [19].

Along with microporoes, carbon sorbents have porous pores that make the main contribution to the adsorption of large organic substances from solutions and used for transporting these substancies. These pores are the so-called mesopores from 1.6 to 100 nm and macropore (over100 nm). In adsorption of gases, vapors or liquids this type of Pore plays an important role. They have little influence in the adsorption of gases. Macropores of carbon sorbents mainly play the role of connecting channels for transporting the sorbed substance from the surface of the material to the sorbing pores.

The criterion for the development of the inner surface of the pores, as well as one of the main indicators of sorption capacity, is the specific surface of the sorbent. Therefore, in the manufacture of carbon tablets, the possibility of one or another production method to obtain a product with a high specific surface development is important. For activated carbons with a high degree of purification, the value of the specific surface can reach up to 1500 m^2/g [20]. In mesopores, sorption forces do not act in the pore volume; sorption occurs at some insignificant distance from the surface and has a polymolecular or monomolecular nature of interaction.

1.4 Parameters and conditions for the manufacture of tablets

1.4.1 Tablet manufacturing technology

The technology for obtaining tablets includes the following main stages:

- Press powder preparation;
- Tablets pressing;
- Tablets sintering.

At each stage of production, the main characteristics of the finished product laid down.

Press powder preparation

The raw material for pressing "raw" tablets is a press powder – a powder with specified physical and chemical properties. To obtain such characteristics as fluidity or porosity, a mixture is prepared from the press powder, which may include a soft blowing agent and a plasticizer, in certain proportions. Plasticizers are substances that are introduced into the composition of polymeric materials to impart (or increase) elasticity or plasticity during processing and operation. Plasticizers allow the dispersion of ingredients, reduce temperature of compositions, improve frost resistance of polymers, but some times worsen its heat retention. Most plasticizers have the ability to improve the fire, light and heat reactivity of polymers. For a uniform distribution of powders in volume, they are pre-mixed. There are dry mixing methods and wet mixing methods using additional liquid.

Tablets pressing

The finished press powder poured into a special mold. Next, the form with the press powder fed to the tablet-pressing machine. Tablets are pressed under certain pressure and holding time. The resulting tablets are unloaded from the press into containers.

Tablets sintering

Tablets are sintered in a high-temperature furnace, which usually consists of 4 sections.

In the first section, the binding component is removed. As a result of heating, the process of moisture evaporation and removal of gaseous impurities from the system through pipes takes place.

In the second section, the tablets are preheated.

In the third section, high-temperature processing of tablets takes place. While moving through the zones of the third section, sintering of the substance occurs.

The fourth section is a heat exchanger, to the outer walls of which steel coils attached, in which water circulates.

After sintering, containers with sintered tablets fed to a grinding machine.

1.4.2 Effect of heat treatment on the porosity of carbon tablets

Traditional technologies for the production of carbon adsorbents include two stages of thermal treatment of carbon-containing raw materials - carbonization (pyrolysis) and activation (gasification), during which the structure of adsorbing pores formed [21]. Activation methods are divided into the following three groups:

1. Steam-gas method of activation of pre-carbonized organic substances. This is the so-called physical activation or activation by oxidation;
2. Activation of coals by carbonization with the addition of reactive inorganic substances is chemical activation or activation by pyrolysis;
3. Mixed method, which includes treatment with chemical reagents and activation by oxidation.

The latter method has not found wide application in the production of carbon sorbents.

On carbonization stages, low volatile substances removed from the material and its internal structure rebuilt, associated with an increased true density. At this stage of carbonization at the stage of carbonization, low molecular volatile substances removed from the carbon-containing material and its internal structure rebuilt, as well as its internal structure rebuilt that is also attributed to an uplift in true density: The actual topochemical transformation of the raw material takes place in the current stage, as it is now. It is possible to see how the topochemical transformation of the raw material takes place. In this way, it leads to the formation of ultramicropores [22].

The gas activation of gases typically uses air, water vapor, and carbon dioxide. A selective air activation is possible, but there are chances of external burning. Air Activation is selective, but there is a risk of external burning in the tablets. The preference is given to water vapor and carbon dioxide.

This is why the traditional technology for producing carbon sorbents from coals includes rather energy-intensive stages of carbonization (temperature 650 –700 °C, time interval of several hours) and oxidative action (Temperature 800 –1000 °C), that are determined by high costs. The raw materials for activated carbons are carbonized natural materials such as hard coal, peat coke, etc. Activation occurs by the steam-gas method. Due to the high proportion of volatile components, these materials easily activated [23]. For example, graphite has a low proportion of volatile components, as a result of which its activation is impossible.

When coals activated by chemical methods, raw materials are most often non-carbonized materials, for example, peat. They mixed with inorganic activating agents and then placed in a high temperature environment.

3. Financial management, resource efficiency and resource saving

The purpose of the thesis: to study the sorption capacity of carbon-based tablets for hydrogen sorption.

The objective of the section "Financial management, resource efficiency and resource saving" is to determine the prospects and success of a research project to study the sorption capacity of carbon-based tablets. To achieve this objective, it is necessary to solve the following tasks:

– identify potential consumers of research results;
– analyze competitive technical solutions
– perform a SWOT analysis: describe the strengths and weaknesses of the project, identify opportunities and threats for project implementation
– assess the degree of readiness of scientific development for commercialization;
– build a calendar plan for the work of a research project;
– calculate research budget;
– determine the resource, financial, budgetary, social and economic efficiency of the study.

3.1 Potential consumer of the research results

In the process of writing the work, potential consumers of the research results were identified. In the future, the target market will be automakers, companies in the energy sector, as well as organizations involved in the production of robotics and drones. It is possible to segment the service market for the use of a particular method of hydrogen storage in relation to the level of gas consumption. The segmentation results are presented in Table 3.1

Table 3.1 – Segmentation of the service market

		Hydrogen storage method		
		Gaseous H_2 (300 K, 10 MPa)	Liquid H_2 (20,4 K)	Sorbated H_2 in tablets
Volumes of hydrogen consumption	Very high (hundreds of tons)			
	High (tons)			
	Low (kilograms)			

From the analysis of the table, it can be concluded that the volumes of use of hydrogen stored in carbon-based tablets have the smallest values. This is due to the insufficiently well developed technology for producing carbon press compositions. Taking into account the fact that the method of storing hydrogen in tablets is the safest and most optimal, and also in connection with the development of hydrogen energy, the need for this storage method will only grow in the near future.

3.2 Analysis of competitive technical solutions

To analyze competitive technical solutions, it is worth considering the above methods of hydrogen storage: gaseous, liquid, sorbed.

Storage of gaseous hydrogen is carried out in gas holders, natural and artificial underground storage facilities. Storage of gaseous hydrogen at a pressure of up to 100 MPa takes place in welded vessels with multilayer walls. Gaseous hydrogen is transported in vessels under pressure up to 20 MPa. One of the main problems of such storage is the high mass of the cylinder, for example, cylinders weighing 20-33 kg are used to store 1 kg of hydrogen.

The advantage of storing hydrogen in the liquid state is a significant reduction in the volume of hydrogen (up to 500 times) compared to the gaseous state. However, hydrogen can be in a liquid state only in a narrow temperature range from -253 ºC to -256 ºC, which requires the organization of cryogenic systems, which complicates the storage of hydrogen. The use of sorption systems is possible in the case of storing a small supply of hydrogen. Their advantage is the absence of hydrogen in the gaseous state - all hydrogen enters into contact with the sorbent and is absorbed by it.

Analysis of competitive technical solutions is determined by the formula [32]:

$$C = \sum W_i \cdot S_i, \quad (3.1)$$

where C is the competitiveness of a scientific development or a competitor;

W_i – criteria weight (in fractions of a unit);

S_i – score of the i-th criteria.

The scorecard of the analysis is presented in Table 3.2. The position of the development and competitors is assessed for each indicator by an expert on a five-point scale, where 1 is the weakest position, and 5 is the strongest. The weights of the indicators, determined by an expert, should add up to 1.

Table 3.2 – Scorecard for comparing competitive technical solutions (developments)

Criteria for evaluation	**Criteria weight**	**Score**			**Competitiveness**		
		P_f	P_{c1}	P_{c2}	C_f	C_{c1}	C_{c2}
1	2	3	4	5	6	7	8
Technical criteria for evaluating resource efficiency							
1. Complexity of implementation	0,15	3	4	4	0,45	0,6	0,6
2. The need for cooling	0,2	5	4	3	1	0,8	0,6
3. Reliability	0,1	5	4	3	0,5	0,4	0,3
4. Safety	0,2	5	3	3	1	0,6	0,6
5. The need for material resources	0,1	3	5	4	0,3	0,5	0,4
6. Weight and size parameters	0,05	5	3	4	0,25	0,15	0,2

Table 3.2 – Continuation

Economic criteria for evaluating efficiency							
1. Competitiveness of the method	0,05	4	4	4	0,2	0,2	0,2
2. Development costs	0,05	3	5	5	0,15	0,25	0,25
3. Estimated service life	0,1	3	4	4	0,3	0,4	0,4
Total	1				**4,15**	**3,90**	**3,55**

Based on the analysis, it can be concluded that the developed model has the advantage of ease of use, functional power and versatility.

3.3 SWOT analysis

SWOT analysis is a summary table illustrating the relationship between internal and external factors of the company. The purpose of this analysis is to describe the strengths and weaknesses of the project, to identify opportunities and threats for the implementation of the project that have emerged or may appear in its external environment.

Table 3.3 shows the SWOT analysis matrix for the production of press powder, compression and firing of carbon-based tablets.

Table 3.3 – SWOT matrix, first stage

	Strengths of the project: S1. Safety in storage and use. S2. Technical simplicity of the implementation of the method. S3. During the manufacturing process, the possibility of clogging the vacuum equipment is excluded. S4. Low cost components. S5. Environmental friendliness of the product	**Weaknesses of the project:** W1. Carbon black does not retain its shape well without a plasticizer after pressing. W2. Individual selection of the pressure value of the press and the exposure time of the tablets

Table 3.3 – Continuation

Opportunities: O1. Possibility of implementation in mass production. O2. Increasing demand for the technology due to the wide range of applications. O3. Multiple use without regeneration	Ease of use, obtaining results in a short time, facilitates the introduction of the technique into mass production.	All of these disadvantages can adversely affect the possibility of introduction into mass production.
Threats: T1. Lack of interest from large investors. T2. Loss of relevance due to the large number of competitive technologies. T3. Lack of demand for technology.	Small expenses for correcting errors, due to the possibility of influencing the process during formation, also the possibility of making a profit in a short time.	Dangerous factors and the lack of a developed methodology associated with the novelty of the method may affect the interest of investors.

Thus, based on the results of the SWOT analysis, it can be concluded that the difficulties and problems that this research project may encounter in one way or another can be solved due to the existing strengths of the development.

3.4 Project planning

The work on the topic includes the following steps:

1) Preparation of terms of reference;
2) Study of the problem, literature review;
3) Work scheduling;
4) Conducting experiments;
5) Processing of received data;
6) Obtaining the results of calculations of true density and critical pressure of pressing;
7) Report design.

To carry out the final qualifying work, a working group was formed, which includes a supervisor and a student.

To optimize work, it is convenient to use the classical method of linear planning and control. The result of such planning is the preparation of a linear schedule for the implementation of all work. The calculation of the parameters of the linear schedule requires the determination of the duration of the work. In the absence of time standards for carrying out certain types of work, probabilistic estimates are used. The procedure for compiling stages and works is given in Table 3.4.

Table 3.4 – List of stages, works and distribution of performers

Main stages	**№ work**	**Content of works**	**Performers**
Development of technical specifications	1	Drafting and approval of technical specifications	Scientific supervisor
Choice of research direction	2	Study of the problem, literature review	Scientific supervisor, student
	3	Work scheduling	Student
Theoretical and experimental studies	4	Conducting experiments	Scientific supervisor, student
	5	Processing of received data	Student
	6	Obtaining the results of calculations of true density and critical pressure of pressing	Student
Generalization and evaluation of results	7	Drawing up an explanatory note	Student

3.4.1 Determination of the complexity of the work

To optimize the work, we use the classical method of linear planning and control, as a result, we will draw up a linear schedule for the execution of all work.

To determine labor costs, you first need to set the minimum possible complexity of the stage and the maximum possible, then the expected labor intensity is determined by the formula:

$$t_{exp\ i} = \frac{3t_{min\ i} + 2t_{max\ i}}{5}, \qquad (3.2)$$

где $t_{\exp i}$ – expected labor intensity of the i-th work, person-days; $t_{min\ i}$ – the minimum possible labor intensity of performing a given i-th work (optimistic assessment: assuming the most favorable set of circumstances), person-days; $t_{max\ i}$ – the maximum possible labor intensity of performing a given i-th work (pessimistic assessment: assuming the most unfavorable set of circumstances), person-days.

Based on the expected labor intensity of the work, the duration of each work in working days is determined, taking into account the parallel execution of work by several performers:

$$T_{w_i} = \frac{t_{exp\ i}}{\mathrm{N}_i}, \qquad (3.3)$$

where T_{w_i} – duration of one work, working days; $t_{exp\ i}$ – expected labor intensity of one work, person-days; N_i – the number of performers performing the same work at the same time at this stage, pers.

3.4.2 Development of a research schedule

Since the project is relatively small, it is optimal to build a tape schedule of work for greater clarity and convenience. The Gantt chart is a horizontal strip chart, on which the work on the topic is presented as long time intervals, characterized by the start and end dates of the work.

Before building a Gantt chart, let's determine the duration of the work of each stage in calendar days. The calculation begins with the determination of the calendar coefficient:

$$k_{\mathrm{c}} = \frac{T_{\mathrm{c}}}{T_{\mathrm{c}} - T_{\mathrm{d}} - T_{\mathrm{h}}}, \quad (3.4)$$

where T_{c} – number of calendar days in a year; T_{d} – number of days off in a year; T_{h} – number of holidays in a year.

$$k_{\mathrm{c}} = \frac{T_{\mathrm{c}}}{T_{\mathrm{c}} - T_{\mathrm{d}} - T_{\mathrm{h}}} = \frac{365}{365 - 104 - 14} = 1{,}478$$

Knowing the coefficient, you can determine the duration of work in calendar days:

$$T_{\mathrm{c}i} = T_{\mathrm{w}i} \cdot k_c, \quad (3.5)$$

where T_{ci} – duration of the i-th work in calendar days; T_{wi} – duration of the i-th work in working days; k_c – calendar coefficient.

Using the above formulas, we will issue the calculation in the form of table 3.5.

Table 3.5 – Time indicators for the engineering project

Stage	Labor intensity of work			Performers	Duration of work in working days, $T_{\mathrm{w}i}$	Duration of work in calendar days, T_{ci}
	t_{min}, person-days	t_{max}, person-days	$t_{exp\ i}$, person-days			
1	4	6	4.8	Scientific supervisor	4,8	8
2	7	12	9	Scientific supervisor, student	4,5	7
3	4	6	4.8	Student	4,8	8
4	10	14	11,6	Scientific supervisor, student	5,8	9
5	14	20	16,4	Student	16,4	25
6	7	14	9,8	Student	4,9	8
7	7	10	8,2	Student	8,2	13
Total						78

Based on Table 3.4.2, a Gantt chart was built, which is presented in Table 3.6.

Table 3.6 – Calendar schedule (Gantt chart) of the study

№	Type of work	Performers	T_{ci}, calendar days	Duration of work, week								
				March			April			May		
				1	2	3	1	2	3	1	2	3
1	Drafting and approval of technical specifications	Scientific supervisor	8	■								
2	Study of the problem, literature review	Scientific supervisor, student	7		■							
3	Work scheduling	Student	8		■	■						
4	Conducting experiments	Scientific supervisor, student	9			■	■					
5	Processing of received data	Student	25				■	■	■			
6	Obtaining the results of calculations of true density and critical pressure of pressing	Student	8							■	■	
7	Drawing up an explanatory note	Student	13								■	■

3.5. Project's budget

The project budget consists of material costs, the basic salary of the study performers, deductions to off-budget funds and overhead costs.

3.5.1 Material costs

The calculation of material costs is made according to the formula:

$$C_m = (1 + k_T) \sum_{i=1}^{m} Pr_i \cdot N_{expi} \quad (3.6)$$

where *m* – the number of types of material resources consumed; N_{expi} – the amount of material resources planned for use; Pr_i – price of a material resource per unit; k_T – coefficient taking into account transport and procurement costs, the value of which varies from 15 to 25%.

Electricity costs are calculated as follows:

$$C_{el} = T_{el} \cdot P \cdot F_{ut} \quad (3.7)$$

where T_{el} – electricity tariff, for Tomsk for 2022 the tariff is 3.85 rubles/(kWh); *P* – equipment power, used equipment power supply is 180 W; F_{ut} – equipment use time, use time 496 hours.

Calculation:

$$C_{el} = 3.85 \cdot 0.18 \cdot 496 = 343.73 \text{ rub}$$

Table 3.7 – Material costs

Name	Unit of measurement	Quantitieso	Unit price, rub.	C_m, rub
Paper A4	pack	1	499 [33]	499
Electricity	W	89.3	3,85	343,73
Technical carbon	g	20	0,211 [34]	4,22
Ethanol	ml	300	0,2 [35]	60
	Total			906,95

3.5.2 Special equipment costs

When performing study, personal equipment was used. Calculate the amount of depreciation:

$$D = \sum_{i=1}^{n} \frac{C_{eq} \cdot R_D \cdot g_i \cdot t}{F_{eff}} \quad (3.8)$$

where C_{eq} – cost of the type of equipment; R_D – annual depreciation rate; g_i – number of pieces of equipment; t – equipment operating time; F_{eff} – effective fund of equipment operation time.

In work, the special equipment is a laptop worth 60,000 rubles. Depreciation rate 25%. Equipment use time 62·8/24 = 21 days.

$$D = \frac{60000 \cdot 0.25 \cdot 1 \cdot 21}{251} = 1255 \text{ rub}$$

3.5.3 Basic and additional salaries of study performers

The salary of performers of the study consists of the main and additional:

$$S_{sal} = S_{\text{base}} + S_{add}, \quad (3.9)$$

where S_{base} – basic salary; S_{add} – additional salary (12-20% of the basic one).

The basic salary can be defined as follows:

$$S_{base} = S_{\text{day}} \cdot T_{\text{w}}, \quad (3.10)$$

where T_{w} – duration of work performed by a scientific and technical worker; S_{day} – average daily salary of a worker, rub.

The average daily salary calculated by the formula:

$$S_{day} = \frac{S_m \cdot \text{M}}{F_{\text{d}}}, \quad (3.11)$$

where S_m – monthly salary of a worker, rub.; M – the number of months of work without vacation during the year: with a vacation of 24 working days M = 11.2 months, 5-day week; on vacation at 48 working days M = 10.4 months, 6-day week; F_{d} – actual annual fund of working time of scientific and technical personnel, working days

Table 3.8 – Estimated annual fund of working hours

Working time indicators	**Scientific supervisor**	**Student**
Calendar number of days	365	365

Table 3.8 – Continuation

Number of non-working days - days off - holidays	 52 14	 52 14
Loss of working time - vacation - absenteeism due to illness	 48 -	 48 -
Actual annual fund of working time	251	251

Calculation of the average daily salary and basic salary for a supervisor (salary of an associate professor, candidate of science 37,700 rubles):

$$S_d = \frac{49010 \cdot 10.4}{251} = 2030.7 \text{ rub}$$

$$S_{base} = 2030.7 \cdot 32 = 64982.4 \text{ rub}$$

For a student (in calculations, it is assumed that the student's salary is taken equal to the minimum salary of 13,890 rubles):

$$S_d = \frac{18057 \cdot 10.4}{251} = 748.2 \text{ rub}$$

$$S_{base} = 748.2 \cdot 32 = 52374 \text{ rub}$$

Table 3.9 – Calculation of the basic salary

Performers	S_{tr}, rub.	k_r	S_m, rub.	S_d, rub.	T_w, w. days	S_{base}, rub.
Scientific supervisor	37700	1,3	49019	2030,7	32	64982,4
Student	13890	1,3	18057	748,2	70	52374
Total						89212

The costs of additional salaries for the performers of the topic take into account the amount of additional payments provided for by the Labor Code of the Russian Federation for deviations from normal working conditions, as well as payments related to the provision of guarantees and compensations (when performing state and public duties, when combining work with education, when providing annual paid leave etc.).

$$S_{\text{add}} = S_{base} \cdot k_{\text{add}}, \quad (3.12)$$

where k_{add} – coefficient of additional salaries (at the design stage it is taken equal to 0.14).

Table 3.10 – Total salary of performers

Salary	Scientific supervisor	Student
Basic salary S_{base},rub.	64982,4	52374
Additional salary S_{add}, rub.	9097,5	7332,4
Total salary S_{sal}, rub.	74079,9	59706,4
Total	133786,3	

3.5.4 Contributions to off-budget funds

The amount of deductions to off-budget funds is determined by the formula:

$$S_{\text{nb}} = k_{\text{nb}} \cdot S_{sal}, \quad (3.13)$$

where k_{nb} – coefficient of contributions for payments to non-budgetary funds (pension fund, compulsory medical insurance fund, etc.), varies from 30 to 35%. When calculating, we will assume that k_{nb} = 30.2% for educational and scientific institutions.

From the previous paragraphs, S_{sal} = 133786.3 rubles. Then the amount of deductions will be:

$$S_{\text{nb}} = 0.302 \cdot 133786.3 = 40403.5 \text{ rub}$$

3.5.5 Overhead costs

Overhead costs are calculated using the formula:

$$S_{oc} = k_{\text{oc}} \cdot S_{sal}, \quad (3.14)$$

where k_{oc} – overhead factor, in the calculation we will take equal to 16%.

$$S_{oc} = 0.16 \cdot 135426.0 = 21668.2 \text{ rub}$$

3.5.6 Formation of the budget for the costs of a research project

Based on the calculations, we will compile a table with the received research project costs.

Table 3.11 – Calculation of the research project cost budget

Costs	**Amount, rub.**
Material costs	906,95
Special equipment costs	1255
Salary of the project performers	133786,3
Deductions to off-budget funds	40403,5
Overhead costs	21668,2
Total	198019,95

3.6 Determination of resource efficiency of a research project

3.6.1 Evaluation of the scientific and technical effect

The assessment of the scientific and technical effect is based on the coefficient of the social and scientific effect:

$$H_T = \sum_{i=1}^{3} r_i k_i \tag{3.15}$$

where r_i – weight coefficient of the *i*-th feature of the scientific and technical effect; k_i – quantitative assessment of the *i*-th feature.

Table 3.12 – Weight coefficients of features of scientific and technical effect

Features of scientific and technological effect	Approximate weight coefficients values
Novelty level	0,6
Theoretical level	0,4
Possibility of implementation	0,2

Table 3.13 – Novelty level scores

Novelty level	Characteristics of the level of novelty	Scores
Fundamental	Research results open a new direction in this field of science and technology	8-10
New	Known facts, patterns are explained in a new way or for the first time	5-7
Relatively new	The research results systematize and summarize the available information, determine the ways for further research	2-4
Traditional	The work performed according to the traditional method, the results of the research are for informational purposes	1
No novelty	Получен результат, который был ранее известен	0

Table 3.14 – Significance scores of theoretical levels

Theoretical level of the obtained results	Scores
Establishment of the law; development of a new theory	9-10
Deep development of the problem: multidimensional analysis of relationships, interdependence between facts with the presence of an explanation	7-8
Development of a method (algorithm, program of events, device, innovation, etc.)	3-6
Elementary analysis of relationships between facts with the presence of a hypothesis, simplex forecast, classification, explanation of versions or practical recommendations of a particular nature	0,6-2
Description of individual elementary facts (things, properties and relationships); presentation of experience, observations, measurement results	0-0,5

Table 3.15 – Probability of implementation by time and scale of implementation

Implementation time	Scores
During the first years	5-10
5 to 10 years	3-4
Over 10 years	0-2
Scale of implementation	Scores
One or more businesses	0-2
Industry (Ministry)	3-4
National economy	5-10

The project is evaluated as follows:

- novelty score – 3
- theoretical level significance score – 6
- implementation probability score – 5+2=7

$$H_T = 0,6 \cdot 3 + 0,4 \cdot 6 + 0,2 \cdot 7 = 5,6$$

Table 3.16 – Assessment of the level of scientific and technical effect

The level of scientific and technological effect	Coefficient of scientific and technical effect
Low	1-4
Average	5-7
Relatively high	8-10
High	11-14

Based on Table 3.16, the level of scientific and technical effect is average.

3.6.2 Evaluation of the comparative effectiveness of the study

Efficiency is determined based on the calculation of the integral indicator of the effectiveness of scientific research. Its finding is associated with the definition of two weighted averages:

The integral financial development indicator:

$$I_{\text{findev}}^{\text{impl.}i} = \frac{\Phi_{\text{impl}i}}{\Phi_{max}} \quad (3.16)$$

where $I_{\text{findev}}^{\text{impl.}i}$ – integral financial development indicator; $\Phi_{\text{impl}i}$ – cost of the i-th variant of implementation; Φ_{max} – maximum cost of a research project (including analogues).

The integral indicator of resource efficiency of the implementation variants of the object of study:

$$I_{\text{re}i} = \sum a_i \cdot b_i, \quad (3.17)$$

where $I_{\text{re}i}$ – integral indicator of resource efficiency of the i-th variant of implementation; a_i – weight coefficient of the i-th variant of the implementation; b_i – scoring of the i-th variant of the implementation.

Table 3.17 – Comparative evaluation of the characteristics of project implementation variants

Criteria	**Weight coefficient**	**Current project**	**Analog**
1. Promotes user productivity	0,1	4	3
2. Ease of operation	0,1	3	2
3. Noise immunity	0,15	3	3
4. Energy saving	0,25	5	4
5. Reliability	0,25	5	4
6. Material consumption	0,15	4	4
Total	1	24	20

$$I_{\text{re}_{cp}} = 0.1 \cdot 4 + 0.1 \cdot 3 + 0.15 \cdot 3 + 0.25 \cdot 5 + 0.25 \cdot 4 + 0.15 \cdot 4 = 4$$

$$I_{\text{re}_{a}} = 0.1 \cdot 3 + 0.1 \cdot 2 + 0.15 \cdot 3 + 0.25 \cdot 4 + 0.25 \cdot 4 + 0.15 \cdot 4 = 3.55$$

The integral indicator of the effectiveness of implementation variants ($I_{\text{impl.}i}$) is determined based on the integral indicator of resource efficiency and the integral financial indicator according to the formula:

$$I_{\text{impl}.i} = \frac{I_{\text{re}i}}{I_{\text{findev}}^{\text{impl}.i}} \qquad (3.18)$$

Comparative effectiveness of the project (E_{comp}):

$$E_{comp} = \frac{I_{\text{impl.1}}}{I_{\text{impl.2}}}. \qquad (3.18)$$

Table 3.18 – Comparative efficiency

Criteria	**Current project**	**Analog**
Integral financial development indicator	1	1
Integral indicator of resource efficiency	4	3,55
Integral indicator of the effectiveness	4	3,55
Comparative effectiveness of the project	1	1,13

Comparison of the values of integral performance indicators allows us to understand and choose a more effective solution to the technical problem posed in the master's thesis from the standpoint of financial and resource efficiency.

Thus, it can be concluded that the project under development is a more effective option for solving the task in comparison with the proposed analogue, based on performance indicators.

Section Conclusions

1. An analysis of competitive technical solutions showed that the method under study has an advantage in ease of use and noise immunity.

2. An assessment of the degree of readiness of scientific development for commercialization showed a level above the average, which can be improved through a more detailed study of the commercial component of the project.

3. In the process of planning a research project, a research project management plan was built, the types of work were determined, the start and end dates of work and the composition of participants were set.

4. The project budget amounted to 198019.95 rubles.

Evaluation of the effectiveness of the study showed that the project being developed is a more effective option for solving the problem in comparison with the proposed analogue.

4 Social responsibility

To date, one of the main directions for radical improvement of all preventive work to reduce workplace injuries and occupational morbidity is the widespread introduction of an integrated labor protection management system, that is, by combining disparate activities into a single system of targeted actions at all levels and stages of the production process.

Rules on labor protection and safety are introduced in order to prevent accidents, ensure safe working conditions for workers and are mandatory for workers, managers, engineers and technicians.

The study was conducted in the 10th building of the Tomsk Polytechnic University in laboratory 247.

Production factors are divided into harmful and dangerous. Dangerous is such a production factor, the impact of which, under certain conditions, leads to injury or other sudden, sharp deterioration in health [36]. Harmful is such a production factor, the impact of which on the worker, under certain conditions, leads to illness or reduced ability to work.

4.1 Analysis of dangerous and harmful production factors

Production conditions at the workplace are characterized by the presence of dangerous and harmful factors, which are classified into groups of elements: physical, chemical, biological, psychophysiological.

A student working on a computer is affected by the following factors:

– physical: air temperature and humidity; noise; static electricity; electromagnetic fields of low frequency; illumination; the presence of radiation;

– psychophysiological. Psychophysiological dangerous and harmful production factors are divided into: physical overload (static, dynamic) and neuropsychic overload (mental strain, monotony of work, emotional overload).

Table 4.1 shows the main dangerous and harmful factors that may arise during the study in laboratory 247 of the 10th building of TPU.

Table 4.1 – Dangerous and harmful factors

Factors (GOST 12.0.003-2015 [37])	Regulatory documents
1. Deviation of microclimate parameters	SanPiN 1.2.3685-21 Hygienic standards and requirements for ensuring the safety and (or) harmlessness of environmental factors for humans [38]
2. Increased noise	
3. Insufficient lighting of the working area	SP 52.13330.2016 Natural and artificial lighting. [39]
4. Electricity	GOST 12.1.038-82 Occupational safety standards system (OSSS). Electrical safety. Maximum allowable values of contact voltages and currents [40]
5. Explosion and fire hazard	Federal Law of 22.07.2008 N 123-FL "Technical regulations on fire safety requirements" [41]

The analysis of harmful and dangerous factors is carried out on the basis of the regulatory documents given in Table 4.1.

4.2 Substantiation and development of measures to reduce the levels of dangerous and harmful effects and eliminate their influence when working on a PC

4.2.1 Organizational measures

Personnel are required to know and strictly observe safety regulations. Introductory briefing and briefing at the workplace by a responsible person are mandatory components of personnel training in safety and industrial sanitation [42].

Testing knowledge of safety rules is carried out by the qualification commission or the person responsible for the workplace after training at the workplace. After that, the employee is assigned a qualification group on safety measures corresponding to his knowledge and work experience and a special certificate is issued [42].

Persons serving electrical installations should not have injuries and diseases that interfere with production work. Before starting work, the state of health is established by a medical examination.

4.2.2 Organization of the workplace of the PC operator

The rational layout of the workplace provides for a clear order and consistency in the placement of objects, tools and documentation. As shown in Figure 4.2.1, each object must be within reach of the workspace.

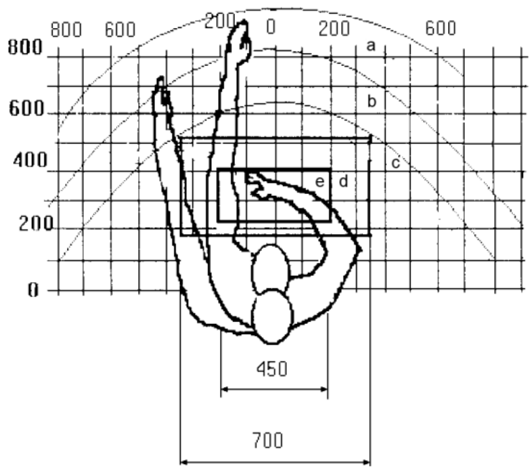

Figure 4.1 - Hand reach zones in the horizontal plane: a - zone of maximum hand reach; b - the reach zone of the fingers with an outstretched hand; c - zone of easy reach of the palm; d - the optimal space for rough manual work; e - optimal space for fine manual work.

The optimal placement of computer peripherals is as follows:

- the display is placed in zone a (in the center);
- keyboard - in zone d, e;
- the system unit is located in zone b (left);
- the printer is in zone a (on the right).

When designing a table for working with a PC, the following requirements are taken into account.

The height of the working surface of the table is 680-800 mm. The height of the working surface for the keyboard is 650 mm. The width and length of the desktop is at least 700 mm and 1400 mm, respectively. Legroom is at least 600 mm in height, width is at least 500 mm; depth at the level of the knees - not less than 450 mm and at the level of outstretched legs - not less than 650 mm [43].

The monitor should be located at the level of the operator's eyes at a distance of 500-600 mm. According to the standards, the viewing angle in the horizontal plane should be no more than 45° to the normal of the screen. It should also be possible to adjust the brightness and contrast of the screen and adjust the monitor rotation in height and tilt angles [43].

The keyboard should be placed on the table surface at a distance of 100-300 mm from the edge, at the level of the operator's elbow with an inclination angle of 15° to the horizontal plane. The keyboard should be comfortable to work with. For example, you can use a mechanical keyboard with concave keys and characters on them in a contrasting color with respect to the color of the keyboard itself.

The work chair must be adjustable in height and angle of rotation, as well as in the angle of inclination of the seat back. Recommended seat height above floor level is 420-550 mm [43].

With monotonous mental work, dim, low-contrast floral shades are chosen that do not scatter attention. When working, requiring intense mental or physical tension, shades of warm tones is recommended, which excite the activity of a person.

4.3 Conditions for safe work

The main parameters characterizing working conditions are: microclimate, noise, vibration, electromagnetic field, radiation, illumination.

4.3.1 Microclimate

The microclimate of industrial premises is determined by the following parameters: air temperature, relative humidity, air velocity. Optimal values of microclimate parameters are set in accordance with [38] and are given in Table 4.3.1

Table 4.2 – Optimal microclimate parameters

Period of the year	Air temperature, ºC	Relative humidity, %	Air speed, m/s
Cold and transitional	23-25	40-60	0,1
Warm	23-25	40	0,1

The microclimate parameters in room 247 of the 10th building of Tomsk Polytechnic University, regulated by the central heating system, have the following values: humidity 40%, air speed less than 0.1 m/s, summer temperature 20-25 °C, winter 19-25 °C. Also, within the framework of the microclimate, it is required to calculate the necessary air exchange of the room [37].

The calculation of the required air exchange is carried out according to the formula [44]:

$$L = n \cdot S \cdot h, \tag{4.1}$$

where L – required ventilation capacity, m^3/h;

n – air exchange rate, $n = 2\ h^{-1}$;

S – room area, $S = 25{,}2\ m^2$;

h – room height, $h = 3{,}2$ m;

The required air exchange is:

$$L = 2 \cdot 24 \cdot 3{,}2 = 153{,}6\ \text{m}^3/\text{h}.$$

This level of air exchange can be provided by the AWENTA WKA12 exhaust fan, the maximum performance of which is 154 m^3/h [45].

Thus, we can conclude that the microclimate parameters in room 247 of the 10th building of TPU meet the established requirements [44].

4.3.2 Noise and vibration

Sources of noise and vibration can be moving parts of electrical equipment, air conditioning and ventilation systems, running fans in a personal computer. Noise has a negative effect on a person: the concentration of a person on work decreases, it negatively affects the nervous system, and labor productivity decreases. The maximum sound level with constant noise is 30 dBA, with non-constant noise - 55 dBA [37].

Noise sources in the laboratory are running fans in personal computers. In modern computers, the noise level created by a working computer is from 20 to 50 dBA and depends on the load on the system. As a rule, work performed on a personal computer does not load the system lightly; therefore, a lower fan speed is required to cool the system, which reduces noise. It is also worth noting that the source of noise may be from outside the laboratory during the organization of natural ventilation. The noise source is not constant; therefore the noise level should not exceed 55 dBA. The noise level near the highway near building 10 is approximately 65 dBA. Since the noise source is located far from the case, the noise level will be somewhat lower than directly at the source. Consequently, the total noise limit in the laboratory 247 of the 10th building does not exceed the established 55 dBA [37].

4.3.3 Illumination of the working area

Eye fatigue can be caused by a lack of light in the work area or excessive lighting, as well as the wrong direction of light. Do not allow the screen to be illuminated by directional bright light sources. Premises with computers should have natural and artificial lighting. For this type of work, the minimum illumination in the laboratory should be 300-500 lux [39].

The calculation of the total uniform artificial illumination of a horizontal work surface is carried out using the luminous flux coefficient method, which takes into account the luminous flux reflected from the ceiling and walls.

The luminous flux is determined by the formula:

$$\Phi = \frac{E_н \cdot S \cdot K_з \cdot Z}{N \cdot \eta}, \tag{4.3}$$

where $E_н$ – normalized minimum illumination equal to 400 lux;

S – the area of the illuminated room, equal to 24 m^2;

$K_з$ – the safety factor taking into account the contamination of the luminaire is taken equal to 1,5;

Z – coefficient of illumination unevenness, equal to 1,1;

N – the number of lamps in the room, equal to 16 pcs.;

η – luminous flux utilization factor.

The luminous flux utilization coefficient shows what part of the luminous flux of the lamps falls on the work surface. It depends on the index of the room *i*, the type of luminaire, the height of the luminaires above the working surface *h* and the reflection coefficients of the walls ρ_w and ceiling ρ_c.

The room index is found by the following formula:

$$i = \frac{S}{h \cdot (A + B)}, \quad (4.4)$$

where A – room length equal to 6 m;

B – room width equal to 4 m;

h – the distance from the lamp to the working surface is 2 m.

Then the room index is:

$$i = \frac{S}{h \cdot (A + B)} = \frac{24}{2 \cdot (6 + 4)} = 1,2.$$

Wall condition - freshly whitewashed with windows without curtains, reflectance ρ_w = 50%. Ceiling condition - light wooden, reflection coefficient ρ_c = 50%. Based on the given values, the luminous flux utilization factor is 56%.

Substituting all quantities into formula (4.3), we obtain the luminous flux:

$$\Phi = \frac{400 \cdot 24 \cdot 1,5 \cdot 1,1}{16 \cdot 0,56} = 1768 \text{ lm}.$$

Such a luminous flux is suitable for a Rexant LED luminaire with a luminous flux of 1800 lm [46].

4.4 Electrical safety

Laboratory 247 of the 10th building of TPU, according to the degree of fire and explosion hazard, belongs to the 1st category of electrical safety [47].

When working with a computer, there is a risk of electric shock. It is forbidden to work with the equipment in conditions of high humidity (relative air humidity exceeds 75% for a long time), high temperature (more than 35 ° C), the presence of conductive dust or floors and the possibility of simultaneously touching metal elements connected to the ground and the metal case of electrical equipment [47].

The computer operator works with electrical appliances: a computer and peripheral devices.

There is a danger of electric shock in the following cases [40]:

– by direct contact with live parts under voltage in case of their malfunction;

– when touching non-current-carrying parts that are energized (in case of violation of the insulation of current-carrying parts);

– when touching the floor, walls that are energized;

– in case of a short circuit in high-voltage units (power supply unit and display scanner unit).

The effect of electric current on the human body is peculiar and versatile. Electric current, passing through the human body, has a thermal, electrolytic and biological effect on various body systems. In this case, there may be violations of the activity of vital human organs: the brain, heart and lungs.

All types of action of electric current on the human body can be combined into two main ones: electrical injuries and electrical shocks.

Electrical injuries are local lesions of the body: burns, metallization of the skin, and mechanical damage to the body.

An electric shock causes excitation of the living tissues of the body by an electric current passing through it, accompanied by involuntary convulsive muscle contractions, including the muscles of the heart and lungs. As a result, various violations of the body's vital functions and even a complete cessation of the activity of the respiratory and circulatory organs can occur.

To ensure electrical safety, the following measures are taken: disconnecting voltage from live parts on which or near which work will be carried out, and taking measures to ensure that it is impossible to supply voltage to the place of work; hanging posters indicating the place of work; grounding of cases of all installations through a neutral wire; coating of metal surfaces of tools with reliable insulation; isolation of current-carrying parts of the equipment using cases that do not conduct current.

4.5 Fire and explosion safety

Laboratory 247 of the 10th building of TPU belongs to category B3 in terms of fire and explosion hazard [13], i.e. to rooms with solid combustible substances, so it is necessary to provide a number of preventive measures.

Possible causes of fire:

– malfunction of current-carrying parts of installations;
– work with open electrical equipment;
– short circuits in the power supply;
– non-compliance with fire safety rules;
– the presence of combustible components: documents, doors, tables.

To prevent the occurrence of a fire, it is necessary to comply with the rules of fire safety at the workplace, conduct fire-fighting briefing of workers and employees.

Fire prevention measures are divided into organizational, operational and regime ones [41, 49].

Organizational measures provide for the correct operation of equipment, fire safety briefing of workers and employees, training of production personnel in fire safety rules [49].

Technical measures include: compliance with fire regulations, norms in the design of buildings, in the installation of electrical wires and equipment, heating, ventilation, lighting [49].

Regime measures include the establishment of rules for the organization of work, and compliance with fire prevention measures [41].

To prevent a fire from short circuits, overloads, the following fire safety rules must be observed:

– exclusion of the formation of a combustible environment (sealing of equipment, air control);

– the use of non-combustible or hardly combustible materials in the construction and decoration of buildings;

– correct operation of the equipment (correct connection of the equipment to the power supply network);

– proper maintenance of buildings and territories (prevention of spontaneous combustion of substances, restriction of hot work);

– training of production personnel in fire safety rules;

– publication of instructions, posters, evacuation plan;

– compliance with fire regulations, norms in the design of buildings, in the installation of electrical wires and equipment, heating, ventilation, lighting;

– proper placement of equipment;

– timely preventive inspection, repair and testing of equipment.

In the event of an emergency it is necessary:

– Notify the management (on duty);

– Call the relevant emergency service or the Ministry of Emergency Situations – tel. 112.

4.10 Emergency Safety

According to [50], an emergency situation (ES) is a situation in a certain territory that has developed as a result of an accident, a dangerous natural phenomenon, a catastrophe, a natural or other disaster that may or have caused human casualties, damage to human health or the environment, significant material loss and disruption of people's living conditions.

According to the nature of the sources, the occurrence of emergency situations is divided into:

– natural;

– technogenic;

– ecological;

– biological and social nature.

Measures to prevent and eliminate the consequences of probable emergency situations that may arise in laboratory 247 of the 10th building of TPU are given in Table 4.3.

Table 4.3 – Measures to prevent and eliminate the consequences of probable emergency situations

№	Emergency situation	Measures to prevent an emergency situation	Measures to eliminate the consequences of emergency situation
1	Fire	Conducting safety briefings, compliance with fire safety rules, control and maintenance of electrical devices	Call the emergency response service at 112, inform the manager and act on his instructions
2	Electric shock	Conducting safety briefings, compliance with electrical safety rules, control and maintenance of electrical devices	
3	Injury from a fall from a height	Conducting safety briefings, careful handling of equipment that may cause injury to personnel, compliance with safety rules when working at a height exceeding the height of one's own body	Conduct an examination of the injuries. In case of serious injuries, call the emergency response service at 112, inform the manager and follow his instructions

4.7 Conclusions on the section "Social responsibility"

The section on social responsibility discusses the main points related to formal safety obligations, which include fire, explosion and industrial safety from the point of view of legal and organizational issues.

The special legal norms of labor legislation related to research work in a sitting position, in particular at the PC, are considered, and organizational measures that contributed to safe work are also considered. Considered and classified harmful and dangerous factors that may affect the person conducting the study:

– increased noise [37];

– deviation of microclimate parameters [38];

– insufficient illumination [39];

– electricity [47].

Laboratory 247 of the 10th building of Tomsk Polytechnic University belongs to the room of moderate fire risk B3 [49], as well as to the 1st category of electrical safety [47].

The most probable emergency situations that can occur in the laboratory 247 of the 10th building of TPU and measures to counter them are considered [50].

Conclusions

1. A comparative analysis of literature data on various methods of hydrogen storage and transportation was carried out. It is shown that carbon materials have the prospect of being used for a safe sorption method of hydrogen storage, and a tablet is presented as a convenient form of using sorbents.
2. It has been established that the porosity of carbon tablets during their manufacture is primarily affected by the pressing pressure and additives introduced into the press powders. Auxiliary material and pressing pressures have been selected.
3. Using the pycnometric method, the true density of the carbon black used in the experiments (1,559 g/cm3) was found, which made it possible, using experimental data on the dependence of the density of the samples obtained on the applied pressure, to determine the coefficients in the pressing equation for this type of carbon. It is shown that the density values calculated using the obtained pressing equation are in good agreement with the data of experimental studies.
4. Using the true density value, the pore volume was determined and the limiting sorption capacity of the manufactured carbon tablets was calculated depending on the composition and pressing pressure before and after heating. It is shown that with increasing pressure, the fraction of free volume in the tablets decreases, and as a result, the sorption capacity decreases. It has been established that in tablets made of pure carbon, as a result of sintering, the pore volume increases by an average of 29%, and in tablets obtained using sodium stearate, it decreases by 27%.

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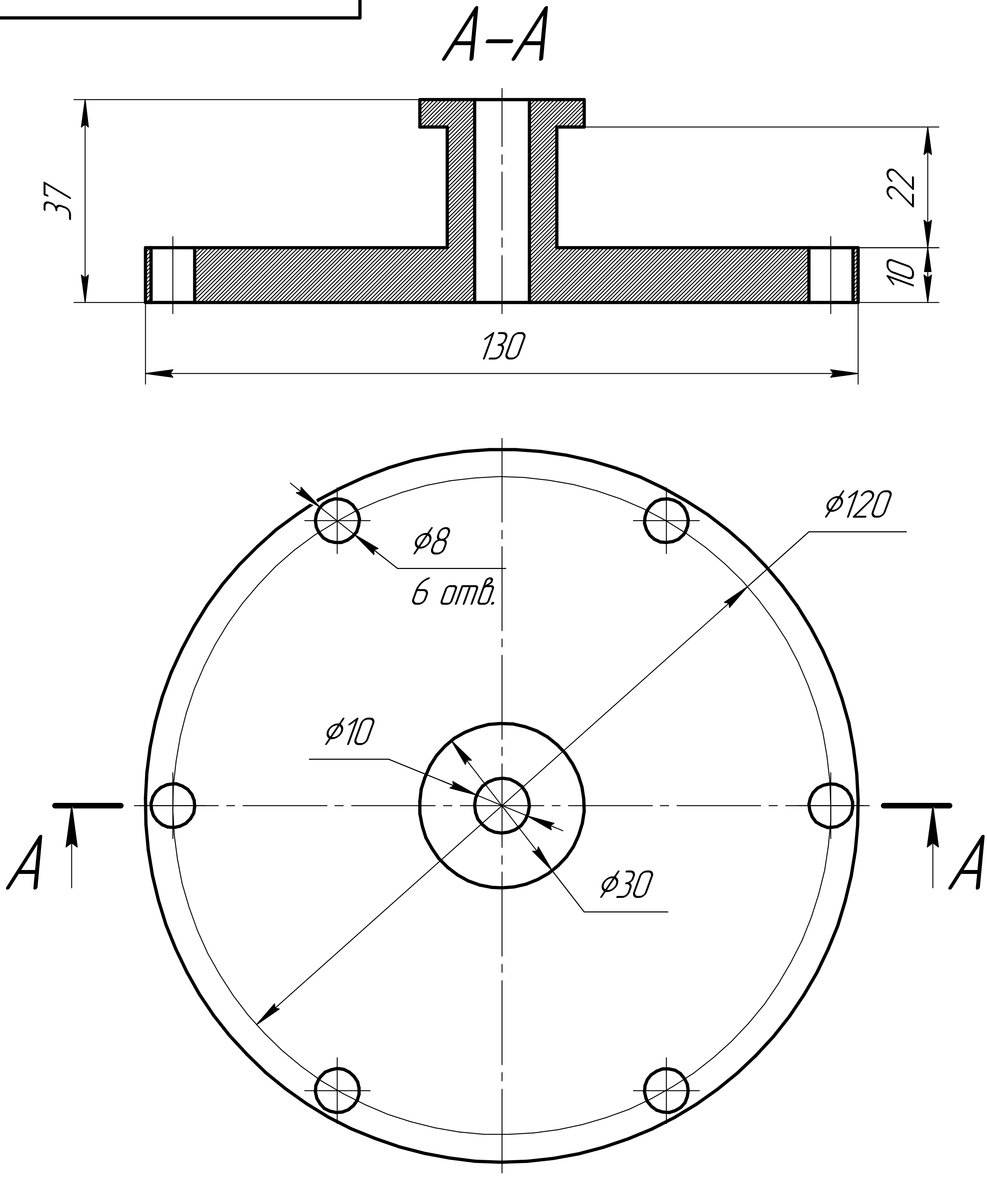

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Н.контр.					
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 Копировал Формат А4