

**KONFERENSIYALAR** COM

ANJUMANLAR PLATFORMASI

**II RESPUBLIKA ILMIY-  
AMALIY KONFERENSIYASI**

**YANGI DAVR ILM-  
FANI: INSON UCHUN  
INNOVATSION G'OYA  
VA YECHIMLAR**

**YANVAR, 2026**

**ISSN 3093-8791**

**ELEKTRON NASHR:**

<https://konferensiyalar.com>





ANJUMANLAR PLATFORMASI

# **YANGI DAVR ILM-FANI: INSON UCHUN INNOVATSION G'OYA VA YECHIMLAR**

**II RESPUBLIKA ILMIY-AMALIY  
KONFERENSIYASI MATERIALLARI**

2026-yil, yanvar

**TOSHKENT-2026**

**Yangi davr ilm-fani: inson uchun innovatsion g'oya va yechimlar.**  
II Respublika ilmiy-amaliy konferensiyasi materiallari to'plami.  
2-jild, 2-son (yanvar, 2026-yil).– 343 bet.

Mazkur nashr ommaviy axborot vositasi sifatida 2025-yil, 8-iyulda  
C-5669862 son bilan rasman davlat ro'yaxatidan o'tkazilgan.

**Elektron nashr:** <https://konferensiyalar.com>

**ISSN:** 3093-8791 (onlayn)

**Konferensiya tashkilotchisi:** "Scienceproblems Team" MChJ

**Konferensiya o'tkazilgan sana:** 2026-yil, 22-yanvar

**Mas'ul muharrir:**

Isanova Feruza Tulqinovna

**Annotatsiya**

Mazkur to'plamda "Yangi davr ilm-fani: inson uchun innovatsion g'oya va yechimlar" mavzusidagi II Respublika ilmiy-amaliy konferensiyasi materiallari jamlangan. Nashrda respublikaning turli oliy ta'lim muassasalari, ilmiy markazlari va amaliyotchi mutaxassislari tomonidan tayyorlangan maqolalar o'rin olgan bo'lib, ular ijtimoiy-gumanitar, tabiiy, texnik va yuridik fanlarning dolzarb muammolari va ularning innovatsion yechimlariga bag'ishlangan.

Ushbu nashr ilmiy izlanuvchilar, oliy ta'lim o'qituvchilari, doktorantlar va soha mutaxassislari uchun foydali qo'llanma bo'lib xizmat qiladi.

**Kalit so'zlar:** ilmiy-amaliy konferensiya, innovatsion yondashuv, zamonaviy fan, fanlararo integratsiya, ilmiy-tadqiqot, nazariya va amaliyot, ilmiy hamkorlik.

**Barcha huquqlar himoyalangan.**

© Scienceproblems team, 2026-yil

© Mualliflar jamoasi, 2026-yil

## MUNDARIJA

### FIZIKA-MATEMATIKA FANLARI

*Abdulbositova Muborak*

YANGI DAVR ILM-FANI: INSON UCHUN INNOVATSION G'OYA VA YECHIMLAR ..... 9-11

*Anvarbekova Ruxsora*

DIFFERENSIAL TENGLAMALARNI YECHISHDA PYTHON KUTUBXONALARINING  
IMKONIYATLARI ..... 12-14

### KIMYO FANLARI

*Kosimova Zuxra*

OKSIDLANISH STRESSI VA UNING TROMBOSITLAR FAOLIYATIGA TA'SIRI ..... 15-18

*Xoshimov Nozimjon, Kosimova Zuxra*

ORGANIZMDAGI OKSIDLANISH STRESS HOLATIDA POLIFENOLLARNING ROLI ..... 19-22

### BIOLOGIYA FANLARI

*Shertoyeva Risliqoy, Mavlanova Sadbarxon*

O'ZBEKISTONNING SHARQIY MINTAQASIDA (NAMANGAN) YASHOVCHI 7–16 YOSHLI  
BOLALAR VA O'SMIRLARDA KO'RISH CHAQRILGAN POTENSIALLARINING YOSHGA XOS  
NORMATIV KO'RSATKICHLARI ..... 23-25

### TEXNIKA FANLARI

*Qurbonov Mahmudjon, Umarov Abdusalam, Kuchkarov Khoshimjon, Khursanova Odina*

STRUCTURAL FEATURES OF POLYAMIDE 6 WITH INCLUSIONS OF IRON OXIDE  
NANOPARTICLES ..... 26-38

*Valixonov Ilyosbek*

KOMPYUTERLI KO'RISH TEXNOLOGIYALARI ASOSIDA IMO-ISHORA TILINI MATNGA  
O'GIRISH TIZIMLARINI TADQIQ ETISH ..... 39-42

*Qurbonov Mahmudjon, Kuchkarov Khoshimjon, Umarov Abdusalam*

WITH STRUCTURE FORMATION AND THE STRUCTURAL COMPOSITION OF THE  
COMPOSITION BASED ON POLYAMIDE WITH IRON OXIDE NANOPARTICLES ..... 43-53

### TARIX FANLARI

*Nurullayeva Nabira*

ISLOHATLAR, YARATILGAN IMKONIYATLAR – XOTIN-QIZLAR UCHUN IMKONIYAT  
ESHIGI ..... 54-56

*Yuldashev Ulugbek*

O'ZBEKISTONDA INKLYUZIV TA'LIM TIZIMI RIVOJLANISHI TARIXI ..... 57-60

*To'ychiyeva Dilnoza, Ergasheva Go'zal*

ZOMIN TUMANIDAGI TURIZM TARMOQLARINING RIVOJI XUSUSIDA ..... 61-64

*Мирзамидинова Шахноза*

ОСВЕЩЕНИЕ ИСТОРИЧЕСКИХ ПРОЦЕССОВ, СВЯЗАННЫХ С ПРОБЛЕМАМИ ЯЗЫКА И  
ОРФОГРАФИИ, В ПУБЛИЦИСТИКЕ АШУРАЛИ ЗОХИРИ ..... 65-67

*Raxmatov Xayrulla*

BUXORO VOHASI MA'MURIY-HUDUDIY BIRLIKLARI VA AHOLISI (XIX ASRNING SO'NGGI  
CHORAGI – XX ASR BOSHLARIDA) ..... 68-71

## **IQTISODIYOT FANLAR**

*Yusupov Nurillo*

BOZOR IQTISODIYOTI SHAROITIDA SANOAT KORXONALARIDA BOSHQARUV FAOLIYATINI TAKOMILLASHTIRISHNING USTUVOR YO'NALISHLARI ..... 72-76

*Mehmonova Shodiyonaxon*

SHHT DOIRASIDA IQTISODIY HAMKORLIKNING RIVOJLANISHI VA UNING O'ZBEKISTON IQTISODIYOTIGA TA'SIRI ..... 77-80

*Ibadullaeva Shokhida*

EXPERIENCES OF DEVELOPED COUNTRIES IN APPLYING MARKETING STRATEGIES IN EXPORTING ENTERPRISES ..... 81-87

*Yusupov Nurillo*

KORXONALARNING BOSHQARUV TIZIMI SAMARADORLIGINI BAHOLASH USULLARI ..... 88-92

## **FALSAFA FANLARI**

*Rahmatullayev Mardonbek*

KIBER MAKONDA SHAXSIY VA JAMOAVIY ERKINLIKNI MUVOZANATLASH STRATEGIYALARI ..... 93-96

*Nabiyev Sherzodjon*

DIGITAL DUNYODA YOSHLAR SHAXSIYATINI SHAKLLANTIRISHDAGI MUAMMOLAR ..... 97-102

*Saydaliyev Ilyosbek*

MURAKKAB MUHITDAN KELGAN YOSHLARDA SOG'LOM TURMUSH TARZINI SHAKLLANTIRISHDA FUQAROLIK JAMIYATINING IJTIMOY-FALSAFIY RO'LI ..... 103-106

*Meliboev Azizjon*

YANGI O'ZBEKISTONDA SIFATLI TA'LIM ORQALI KAMBAG'ALLIKKA QARSHI KURASH VA XALQ FAROVONLIGINI TA'MINLASH ..... 107-111

## **FILOLOGIYA FANLARI**

*Aminov Farrux*

INGLIZ VA O'ZBEK OMMAVIY AXBOROT VOSITALARIDA AXBOROT UZATISHNING MULTIMODAL STRATEGIYALARI VA KOGNITIV MEKANIZMLARI ..... 112-119

*Jo'rayeva Madinaxon*

YANGI DAVR ILM-FANI: INSON UCHUN INNOVATSION G'OYA VA YECHIMLAR: O'ZBEKISTON RESPUBLIKASI VA SUN'IY INTELLEKT SOHASIDAGI INNOVATSIYALAR MISOLIDA ..... 120-124

*Isakova Barchinoy*

JEK LONDONNING "MARTIN IDEN" HAMDA O'TKIR HOSHIMOVNING "NUR BORKI, SOYA BOR" ROMANLARIDAGI POETIK VOSITALAR TAHLILI ..... 125-128

*Азизова Насиба*

ИССЛЕДОВАНИЕ КОНЦЕПТА ЯЗЫКОВОЙ ЛИЧНОСТИ В РУССКОЙ И УЗБЕКСКОЙ КЛАССИЧЕСКОЙ ЛИТЕРАТУРЕ (НА ПРИМЕРЕ А. С. ПУШКИНА, Н. В. ГОГОЛЯ И Л. Н. ТОЛСТОГО АЛИШЕРА НАВОИ, ЗАХИРИДДИНА БАБУРА) ..... 129-134

*Toshboyeva Odinaxon*

INGLIZ VA O'ZBEK INTERNET GAZETA SARLAVHALARIDA LEKSIK-SEMANTIK VA SINTAKTIK VOSITALAR ASOSIDA PRAGMATIK PRESUPPOZITSIYANING IFODALANISHI ..... 135-138

<i>Umirzakova Dilnoza</i> ANIMATSION FILMLAR TARJIMASIDA LINGVOPRAGMATIK OMILLAR: QIYOSIY TADQIQOT .....	139-144
<i>Jabborova Aziza</i> SIYOSIY KOMMUNIKATSIYADA EVFEMIZMLARNING AUDITORIYAGA TA'SIRI .....	145-149
<i>Boykhanov Shukhratjon</i> UNDERSTANDING ENGLISH PROVERBS: LEXICAL, STYLISTIC, PSYCHOLOGICAL, AND PRAGMATIC DIFFICULTIES .....	150-155
<i>Narzulloyeva Maftuna</i> A COMPARATIVE ANALYSIS OF OFFICIAL LETTERS IN ENGLISH AND UZBEK PROSE .....	156-158
<i>Abdullayeva Dildora</i> QUTADG'U BILIG FRAZELOGIZMLARINING SEMANTIK-PRAGMATIK TABIATI VA LISONIY TADQIQI .....	159-162
<i>Umrzaqov Islomjon</i> "JANUB RENESSANSI" DAVRI ASARLARIDA BADIY MAKON VA ZAMON POETIKASI .....	163-165
<i>Fayzullayeva Nozima</i> YANGI DAVR ILM-FANI: INSON UCHUN INNOVATSION G'OYA VA YECHIMLAR .....	166-168
<i>Ergashev Nodirbek</i> SOCIAL INJUSTICE AND MORAL VALUES IN "OLIVER TWIST" BY CHARLES DICKENS .....	169-171
<i>Ubaydullaeva Dilfuza</i> OLIV TA'LIM MUASSASALARIDA BO'LAJAK MUTAXASSISLARDA NUTQ MADANIYATINI RIVOJLANTIRISHNING INNOVATSION MODELLARI (IJTIMOIY-GUMANITAR YO'NALISHDA) .....	172-178
<b>GEOGRAFIYA FANLARI</b>	
<i>Umarov Javohir</i> FARG'ONA VILOYATI YER RESURSLARIDAN QISHLOQ XO'JALIGIDA FOYDALANISH SAMARADORLIGINI KOMPLEKS BAHOLASH .....	179-185
<b>YURIDIK FANLAR</b>	
<i>Hakimboyeva Dildora</i> ELEKTRON HUKUMAT VA MA'MURIY HUQUQ MUNOSABATLARINING TRANSFORMATSIYASI .....	186-188
<i>Самигжоновна Зилола</i> МЕЖДУНАРОДНЫЕ НОРМЫ, РЕГУЛИРУЮЩИЕ ЗАЩИТУ ПРАВ ЧЕЛОВЕКА В СЕТИ ИНТЕРНЕТ .....	189-195
<b>PEDAGOGIKA FANLARI</b>	
<i>Xomidjonov Abrorjon</i> OLIV VA PROFESSIONAL TA'LIMDA PEDAGOGIK INNOVATSIYALARNI TATBIQ ETISH TAJRIBASI .....	196-202

<i>Sodiqova Gulnora</i> KASBIY TA'LIM TIZIMIDA ISH BERUVCHILAR BILAN SAMARALI KOMMUNIKATSIYA STRATEGIYALARI .....	203-208
<i>Soliyeva Gavharoy</i> "HISOBLASH USULLARI" FANI BO'YICHA O'QUV KONTENTI .....	209-212
<i>Isaqov Abduvohid</i> BO'LAJAK O'QITUVCHILARDA METODIK KOMPETENSIYANI RIVOJLANTIRISH: ASOSIY TUSHUNCHALAR VA ZAMONAVIY YONDASHUVLAR .....	213-217
<i>Юсупова Наргиза, Юсупов Дильшод</i> ИННОВАЦИОННЫЕ ТЕХНОЛОГИИ И РОЛЬ ИСКУССТВЕННОГО ИНТЕЛЛЕКТА В ОБУЧЕНИИ ТЕХНИКО-ТАКТИЧЕСКИХ ДЕЙСТВИЙ ЮНЫХ ТАЭКВОНДИСТОВ: АНАЛИЗ ЭФФЕКТИВНОСТИ И ПЕРСПЕКТИВ РАЗВИТИЯ .....	218-221
<i>Ganiyev Elyorbek</i> TALABALARDA HUQUQIY TAFAKKUR VA TAHLILY KO'NIKMALARNI RIVOJLANTIRISHNING ZAMONAVIY METODIKASI .....	222-226
<i>Xabibullayev Alimardon</i> TALABALAR MOBILLIGI VA QO'SHMA TA'LIM ASOSIDA INNOVATSION VA BARQAROR RIVOJLANISH MODELINI SHAKLLANTIRISHNING PEDAGOGIK- INSTITUTSIONAL ASOSLARI .....	227-233
<i>Nigmatova Nozimaxon</i> INGLIZ TILINI O'QITISHDA GENERATIV SUN'IY INTELLEKT TEXNOLOGIYALARINI JORIY ETISHNING XORIJIY AMALIYOTI VA PEDAGOGIK SAMARADORLIGI .....	234-237
<i>Юсупова Наргиза</i> АНАЛИЗ БИОМЕХАНИЧЕСКИХ ПАРАМЕТРОВ АТАКУЮЩИХ ДЕЙСТВИЙ КВАЛИФИЦИРОВАННЫХ ТАЭКВОНДИСТОВ (WT) .....	238-241
<i>Abdullayeva Asila</i> O'ZBEKISTONNING SO'NGGI TARIXI VA FALSAFA FANINI O'QITISHDA DIDAKTIK UYG'UNLIK .....	242-247
<i>Ergasheva Nigora</i> BO'LAJAK BOSHLANG'ICH TA'LIM O'QITUVCHILARINING METODIK KOMPETENSIYASINI SHAKLLANTIRISHDA PEDAGOGIK HAMKORLIKNING METODIK VAZIFALARI .....	248-251
<i>Alimova Mashxuraxon</i> BOSHLANG'ICH SINIF TEXNOLOGIYA TA'LIMI DARSLARIDA TABIIY MATERIALLARDAN BUYUMLAR TAYYORLASHDA KONSTRUKSIYALASH KO'NIKALARINI RIVOJLANTIRISH METODIKASI .....	252-255
<i>G'ofurova Barnoxon</i> TALABALARINING KONSEPTUAL FIKRLASHINI RIVOJLANTIRISHDA OLIY TA'LIMNING METODIK SHART-SHAROITLARI VA PEDAGOGIK IMKONIYATLARI .....	256-260
<i>Axmedov Yodgorbek</i> ICHKI ISHLAR VAZIRLIGI AKADEMIK LITSEYLARI O'QUVCHILARINING MUSTAQIL O'QUV FAOLIYATIDA TINKERCAD PLATFORMASIDAN FOYDALANISH IMKONIYATLARI .....	261-263

<i>Qozaqova Munajat</i> MUHANDISLIK VA KOMPYUTER GRAFIKASI FANINI O'QITISHDA TALABALAR LOYIHALASH KO'NIKMASINI KO'RGAZMALILIK ASOSIDA RIVOJLANTIRISH .....	264-267
<i>Парниева Айгуль</i> АКСИОЛОГИЧЕСКИЙ ПОТЕНЦИАЛ ХУДОЖЕСТВЕННОЙ ЛИТЕРАТУРЫ В ФОРМИРОВАНИИ СОЦИАЛЬНОЙ ОТВЕТСТВЕННОСТИ СОВРЕМЕННОГО СТУДЕНТА .....	268-271
<i>Nosirova Shoiraxon</i> INGLIZ TILIDA KASBIY MULOQOT XULQINING LINGVOKULTUROLOGIK XUSUSIYATLARI .....	272-278
<i>Azizova Mohiniso, G'ulomova Sevara</i> МАКТАБ DARSLARIDA RA'NODOSHLILAR OILASINI O'QITISHDA ZAMONAVIY INTERAKTIV METODLARDAN FOYDALANISH .....	279-281
<i>Jalilova Xolidaxon</i> METHODOLOGY FOR IMPROVING THE EFFICIENCY OF TEACHING ENGLISH USING WEBQUEST TECHNOLOGY .....	282-284
<i>Abduvaxobov Shohruhbek</i> MASOFADAN TA'LIM JARAYONIDA UCHRAYDIGAN AMALIY MASALALAR VA ULARNI BARTARAF ETISH BO'YICHA METODIK YONDASHUVLAR .....	285-287
<i>Аюпов Тимур</i> СОВРЕМЕННЫЕ МЕТОДЫ ОБУЧЕНИЯ ИНОСТРАННЫМ ЯЗЫКАМ В ВУЗАХ РЕСПУБЛИКИ УЗБЕКИСТАН .....	288-290
<i>Tillayeva Nilufar</i> DIALOGIC PEDAGOGY IN ESL WRITING: THE ROLE OF SOCRATIC SEMINARS .....	291-294
<i>Sobirova Feruza</i> BO'LAJAK INGLIZ TILI O'QITUVCHILARIDA DARSNI REJALASHTIRISH KO'NIKMALARINI SHAKLLANTIRISH MUAMMOLARI .....	295-299
<i>Karimova Sadoqat</i> CONCEPTUAL AND METHODOLOGICAL APPROACHES TO TEACHING ENGLISH TO PRESCHOOL CHILDREN IN A MONTESSORI EDUCATIONAL ENVIRONMENT .....	300-302
<i>Солохиддинова Фазилатхон</i> МЕТОДИКА РАЗВИТИЯ КОГНИТИВНЫХ УЧЕБНЫХ ДЕЙСТВИЙ УЧАЩИХСЯ НАЧАЛЬНЫХ КЛАССОВ В АСПЕКТЕ РАЗВИТИЯ ГРАММАТИЧЕСКОГО ПОНЯТИЯ «ИМЯ СУЩЕСТВИТЕЛЬНОЕ» .....	303-306
<i>Sayidova Nilufar</i> ZAMONAVIY MUZEY EKSPOZITSIYALARIDA INTERAKTIV TEXNOLOGIYALARNING ILMIY - AMALIY AHAMIYATI .....	307-310
<i>Ne'matova Mahfuzaxon</i> BOSHLANG'ICH SINIF O'QUVCHISINING NUTQ FAOLIYATINI FAOL RIVOJLANTIRISHDA FE'L SO'Z TURKUMINING TUTGAN O'RNI .....	311-313

## **TIBBIYOT FANLARI**

*Sobirova Mavludaxon*

YANGI DAVR ILM-FANI: INSON UCHUN INNOVATSION G'OYA VA YECHIMLAR .....314-316

*Ахмаджонова Хуршидабону, Рустамова Шахиста*

НАУЧНЫХ ИССЛЕДОВАНИЙ ПО ИЗУЧЕНИЮ НАСЛЕДСТВЕННАЯ

ПРЕДРАСПОЛОЖЕННОСТЬ ВИРУСАМИ ГЕПАТИТА С (НСV) И В (НВV) НА

МОЛЕКУЛЯРНОМ УРОВНЕ .....317-322

*Xoshimov Muslimbek, Karimjonov Jaloliddin, Inomov Kamoliddin, Izatullayeva Mohlaroyim*

O'ZBEKISTONDA NEYRODEGENERATIV KASALLIKLARNING TARQALISH SABABLARI VA

NEYRODEGENERATIV KASALLIKLAR RIVOJLANISHIDA ASTROSITLARDAGI REAKTIV

O'ZGARISHLAR .....323-326

*Мамарова Шодила, Инатуллаева Рано, Сотиболдиева Умида, Кодиржанов Жавохир*

ВИТАМИН D: МЕТАБОЛИЗМ, БИОЛОГИЧЕСКАЯ РОЛЬ, ДЕФИЦИТ И

ПРОФИЛАКТИКА .....327-336

## **PSIXOLOGIYA FANLARI**

*Ismoilov Temurbek*

VERBAL KOMMUNIKATIV KOMPETENSIYANI RIVOJLANTIRISHDA MADANIY VA IJTIMOY

KONTEKSTNING ROLI .....337-342

## TEXNIKA FANLARI

**STRUCTURAL FEATURES OF POLYAMIDE 6 WITH INCLUSIONS OF IRON OXIDE NANOPARTICLES****Qurbonov Mahmudjon**

Namangan State University

Email: mahmudjon [01.11@mail.ru](mailto:01.11@mail.ru)**Umarov Abdusalam Vaxitovich**

Tashkent State Transport University

Tashkent University of Applied Sciences

Email: [abdusalom@inbox.ru](mailto:abdusalom@inbox.ru)**Kuchkarov Khoshimjon Ortiqovich**

Namangan State University

**Khursanova Odina**

Student at Namangan State University

**Annotation:** Polymer composite materials reinforced with nanoscale fillers are increasingly utilized in mechanical engineering due to their ability to replace conventional metallic components operating under friction, moisture, temperature fluctuations, and dynamic loading. Polyamide-6 (PA6) is one of the most promising polymer matrices because of its high strength, elasticity, and wear resistance. However, its practical application is limited by low hardness, thermal expansion, and dimensional instability. In this study, iron oxide (FeO) nanoparticles were introduced into the PA6 matrix to investigate their influence on the structural organization of the polymer using infrared (IR) spectroscopy. The objective was to evaluate how interactions between the aromatic and aliphatic structural fragments of PA6 and FeO nanoparticles affect supramolecular ordering and hydrogen bonding. The IR spectral analysis revealed shifts and intensity changes in the characteristic bands of Amide I, II, III, V, and VI, indicating the disruption and redistribution of hydrogen bonds and partial reorganization of the macromolecular network. The appearance of additional peaks at 823, 886, and 1503  $\text{cm}^{-1}$  and the merging or shifting of bands at 700 and 600  $\text{cm}^{-1}$  showed the formation of new interactions, including imide, immonium, and carboxylate-related structures. With an FeO content of up to 40 wt.%, significant amorphization or transition to the  $\gamma$ -modification was observed. The disappearance of certain C-N vibrational peaks indicated decyclization processes and molecular-level interaction between filler and polymer, accompanied by changes in hydrogen bonding patterns and electrostatic associations. The results confirm that FeO nanoparticles play a structural-regulating role in PA6 composites and can be used for targeted modification of physicochemical and tribological properties relevant to mechanical engineering applications.

**Key words:** Molecular spectrum, polyamide, iron oxide, amide bonds, cleavage, band, hydrogen bonds,  $\pi$ -electron clouds,  $\alpha$ -modification. Polyamide 6; Iron oxide nanoparticles; IR spectroscopy; Polymer composites; Hydrogen bonding; Structural modification; Supramolecular organization; Amorphization; Mechanical engineering materials.

**POLIAMID 6 DA TEMIR OKSID NANOPARTIKULLARI INKLUZIONLARI BILAN STRUKTURAL XUSUSIYATLAR****Qurbonov Mahmudjon**

Namangan davlat universiteti

**Umarov Abdusalam Vaxitovich**

Toshkent davlat transport universiteti

Toshkent amaliy fanlar universiteti

**Qo'chqorov Xoshimjon Ortiqovich**  
Namangan davlat universiteti

**Xursanova Odina**  
Namangan davlat universiteti talabasi

**Annotatsiya.** Nanoskalali to'ldiruvchilar bilan mustahkamlangan polimer kompozit materiallar, ishqalanish, namlik, harorat o'zgarishlari va dinamik yuklanish sharoitida ishlaydigan an'anaviy metall komponentlarni almashtirish qobiliyati tufayli mexanik muhandislikda tobora ko'proq qo'llanilmoqda. Poliamid-6 (PA6) yuqori kuch, elastiklik va aşınma qarshiligi tufayli eng istiqbolli polimer matritsalaridan biridir. Biroq, uning amaliy qo'llanilishi past qattqlik, termal kengayish va o'lchov barqarorligi bilan cheklangan. Ushbu tadqiqotda PA6 matritsasiga temir oksidi (FeO) nanopartikullari kiritilib, ularning polimerning strukturaviy tashkilotiga ta'siri infraqizil (IR) spektroskopiyasi yordamida o'rganildi. Maqsad - PA6 ning aromatik va alifatik strukturaviy fragmentlari bilan FeO nanopartikullari o'rtasidagi o'zaro ta'sirlar supramolekulyar tartib va vodorod bog'lanishlariga qanday ta'sir qilishi ekanligini baholashdir. IR spektral tahlili Amide I, II, III, V va VI ning xos bandlarida siljishlar va intensivlik o'zgarishlarini ko'rsatdi, bu vodorod bog'lanishlarining buzilishi va qayta taqsimlanishini hamda makromolekulyar tarmoqning qisman qayta tashkil etilishini ko'rsatadi. 823, 886 va 1503  $\text{sm}^{-1}$  da qo'shimcha piklarning paydo bo'lishi va 700 va 600  $\text{sm}^{-1}$  da bandlarning birlashishi yoki siljishi yangi o'zaro ta'sirlar, jumladan imid, immoniy va karboksilatga oid tuzilmalarni shakllanishini ko'rsatdi. FeO miqdori 40 vazn foizgacha bo'lganida, sezilarli amorfizatsiya yoki  $\gamma$ -modifikatsiyaga o'tish kuzatildi. Ayrim C-N tebranish piklarining yo'qolishi to'ldiruvchi va polimer o'rtasidagi molekulyar darajadagi o'zaro ta'sir jarayonlarini, vodorod bog'lanishlari naqshlari va elektrostatik assotsiatsiyalaridagi o'zgarishlar bilan birga kelayotgan dekitsiklizatsiya jarayonlarini ko'rsatdi. Natijalar shuni tasdiqlaydi ki, FeO nanopartikullari PA6 kompozitlarida strukturaviy tartibni boshqaruvchi rol o'ynaydi va mexanik muhandislik ilovalari uchun fizik-kimyoviy va tribologik xususiyatlarni maqsadli modifikatsiya qilishda foydalanilishi mumkin.

**Kalit so'zlar:** Molekulyar spektr, poliamid, temir oksidi, amid bog'lari, parchalanish, band, vodorod bog'lanishlari,  $\pi$ -elektron bulutlari,  $\alpha$ -modifikatsiya. Poliamid 6; Temir oksidi nanopartikullari; IR spektroskopiyasi; Polimer kompozitlari; Vodorod bog'lanishi; Strukturaviy modifikatsiya; Supramolekulyar tashkilot; Amorfizatsiya; Mexanik muhandislik materiallari.

DOI: <https://doi.org/10.47390/yl-dif-y2026v2i2/n06>

In modern mechanical engineering, polymer composite materials are increasingly used every year. This is mainly due to the fact that the parts of moving joints made of metals and their alloys do not meet the requirements for the units of the mechanical engineering industry. The latter are used in stressful conditions: the presence of friction, moisture, temperature fluctuations, significant dynamic and alternating loads. This led to the fact that traditional materials in moving joints were gradually replaced by more progressive polymer composite materials. Today, an effective way to improve the performance properties of polymers is their modification with nano- and submicron sized fillers, which allow targeted regulation of the processes of formation of its supramolecular structure and, consequently, the properties of the resulting material.

In this area, the creation of such materials is especially relevant, among which the most important role is given to polyamide 6 (PA 6), due to its valuable complex of consumer properties: high strength, elasticity, resistance to abrasion. However, the use of polyamides as structural materials, for example, in friction units, is limited due to their low hardness, increased coefficient of thermal expansion, dimensional instability. Therefore, in order to improve the main performance characteristics of composites, it is very advisable to introduce dispersed metal fillers into the composition of polyamide binders and to study the scientific

principles of creating polymer composite materials based on the study of the structural composition, structure, physicochemical characteristics and the formation of new bonds between the components of the polyamide composite.

The goal The purpose of this work is to determine the nature of the interaction of structural aromatic fragments of different structures in the structure of polyamide with FeO nanoparticles using IR spectroscopy to assess the influence of iron oxide nanoparticles on structural features and possible methods for targeted regulation of their properties.

Recent reviews and fundamental studies demonstrate that polymer nanocomposites realize their enhanced properties through three interrelated mechanisms: (1) nucleation and modification of crystallization behavior by nanoparticle surfaces, (2) formation of a modified interphase with distinct physicochemical properties, and (3) mechanical reinforcement due to efficient stress transfer at well-bonded interfaces [12,13,14,26,32]. Specifically for polyamide matrices, a number of experimental works report that nanoscale inorganic fillers alter the PA6 crystallization kinetics, shift the balance between  $\alpha$ - and  $\gamma$ -crystalline forms, and may increase overall crystallinity when dispersion and interfacial adhesion are optimized [16,17,25,34]. These structural modifications directly affect macroscopic characteristics such as stiffness, dimensional stability and wear resistance — properties critical for mechanical engineering applications [18,30,31]. [12,13,16,17,25,34,18,30]

Metal-oxide nanoparticles (including various forms of iron oxides) have attracted interest because their surface chemistry enables specific interactions with amide groups of polyamides (hydrogen bonding, dipolar interactions), which in turn influence supramolecular ordering and interlamellar cohesion [27,28,33]. Experimental IR and spectroscopic investigations indicate that introduction of Fe-containing fillers often leads to subtle shifts in characteristic vibrational bands (amide I, II and associated ring vibrations), reflecting changes in hydrogen-bonding patterns and local conformational distribution of polymer chains adjacent to the filler surface [19,35,11]. Such spectroscopic fingerprints are therefore used as direct evidence of polymer–filler interfacial interaction and can be correlated with XRD-derived crystallographic changes and thermal analysis data. [27,28,33,19,35,11]

Regarding methods of structural characterization, combined application of vibrational spectroscopy (FTIR/IR), X-ray diffraction, and thermal techniques (DSC, TGA) is widely accepted for extracting complementary information: FTIR probes local chemical environment and bonding, XRD reveals long-range crystalline order and phase composition, while DSC/TGA quantify changes in thermal transitions and stability that follow structural modification [7,9,17,23,35]. In particular, XRD studies on PA6-based nanocomposites demonstrate how diffraction peak positions, intensities and crystallite sizes respond to nanoparticle-induced nucleation and growth processes; these diffraction-based indicators are commonly used to quantify crystallinity modification and crystallite orientation [16,17,25]. [7,9,17,23,35,16,25]

Many applied investigations also emphasize that the benefits of nanoparticle addition depend critically on filler characteristics (phase polymorph, particle size distribution, surface functionalization), dispersion method (melt mixing, solution blending, in-situ polymerization), and concentration threshold beyond which agglomeration negates positive effects [14,15,20,24,26]. For iron-oxide specifically, researchers note differences in behaviour between FeO, Fe<sub>3</sub>O<sub>4</sub> and Fe<sub>2</sub>O<sub>3</sub> phases owing to distinct surface energy and magnetic properties that affect dispersion and interparticle interactions; control of these parameters is

essential to achieve uniform nanoparticle distribution and to avoid stress concentrators that degrade tribological performance [27,28,31]. [14,15,20,24,26,27,28,31]

Tribological studies comparing neat PA6 and filled PA6 systems report consistent reductions in friction coefficient and wear volume for well-dispersed nanofiller systems, while excessive filler loading or poor dispersion can produce abrasive behavior and increased wear [18,30]. These outcome trends motivate the present focus on both spectroscopic evidence of interfacial bonding and on XRD/thermal corroboration of crystallinity changes as predictors of tribological improvement in PA6–FeO composites. [18,30]

The present study builds on prior experimental and review literature, applying IR spectroscopy as the principal tool to interrogate modifications in vibrational spectra associated with aromatic structural fragments and their interaction with FeO nanoparticles — an approach supported by previous IR- and XRD-based analyses on polyamide nanocomposites [19,11,16]. By combining spectroscopic data with complementary structural information (XRD patterns and thermal indicators cited in the literature), we aim to (i) identify specific spectral markers of polymer–FeO interaction, (ii) quantify associated changes in crystallinity and supramolecular organization, and (iii) propose targeted strategies for property regulation via controlled filler characteristics and processing routes [11,16,17,25,35]. [19,11,16,17,25,35]

In summary, the literature shows a coherent framework: nanoscale metal-oxide fillers (including iron oxides) can be used to tune the supramolecular organization and crystallinity of PA6-based composites, and spectroscopic methods—particularly IR—together with diffraction and thermal techniques, provide the necessary diagnostic toolkit to link microscopic interactions with macroscopic performance [12,13,14,16,17,19,25,27,28,35]. The current work applies this framework to PA6 + FeO systems, with the goal of elucidating mechanisms of interaction for rational design of high-performance mechanical engineering materials. [12,13,14,16,17,19,25,27,28,35]

## RESEARCH METHODS

The IR spectrum of the sample was recorded in the 400–4000  $\text{cm}^{-1}$  range on an IRTracer-100 (SHIMADZU CORP., Japan, 2017) spectrometer using a MIRacle-10 diamond/ZnSe prism. The absorption spectra were confirmed according to literature data.

To ensure high spectral resolution and reproducibility of vibrational band assignments, each measurement was conducted by accumulating no fewer than 32 scans at a spectral resolution of 2  $\text{cm}^{-1}$ . Prior to analysis, the instrument was calibrated using a standard polystyrene film to verify the accuracy of characteristic absorption peaks in the fingerprint region. Background correction was performed before each recording to eliminate atmospheric contributions of  $\text{CO}_2$  and  $\text{H}_2\text{O}$  vapor, which can affect the transmittance in the 2300–2400  $\text{cm}^{-1}$  and 3200–3700  $\text{cm}^{-1}$  regions, respectively.

All spectra were recorded in attenuated total reflectance (ATR) mode to avoid additional sample preparation steps and minimize structural distortion of the polymer matrix. The use of a diamond/ZnSe prism provided chemical inertness and a high refractive index, which allowed the acquisition of spectra with enhanced signal-to-noise ratio in the region of amide bond vibrations. Special attention was paid to the absorption bands at 1630–1680  $\text{cm}^{-1}$  (amide I), 1510–1580  $\text{cm}^{-1}$  (amide II), and 1230–1280  $\text{cm}^{-1}$  (amide III), which are sensitive to supramolecular ordering and hydrogen bonding between polyamide chains and iron oxide nanoparticles.

Baseline correction and normalization of spectra were carried out using IRsolution software (Shimadzu) to enable accurate comparative analysis between filled and unfilled samples. Deconvolution of overlapping bands was performed using Gaussian and Lorentzian fitting functions to identify subtle changes in peak position and intensity. These spectral modifications were further compared with reference data from previously published studies on PA6-based nanocomposites to validate the presence of interaction-induced shifts in vibrational modes.

Quantitative assessment of structural reorganization was performed using peak area ratios of amide I/amide II and the intensity of bands associated with CH<sub>2</sub> wagging and skeletal vibrations. In addition, specific shifts in the spectral region of 500–700 cm<sup>-1</sup> were analyzed to confirm the contribution of Fe–O stretching vibrations, indicating the successful incorporation and interaction of iron oxide nanoparticles within the polymer matrix.

The obtained spectra were interpreted in correlation with XRD and thermal analysis data described in the literature, which allowed the identification of phase-specific structural transformations, changes in crystallinity, and the formation of interfacial bonding between the filler and the polymer matrix. This comprehensive spectroscopic approach made it possible to assess not only the presence of nanoparticles but also their influence on the molecular architecture of the composite material.

## RESULTS AND DISCUSSION

As is known, vibrational IR spectroscopy occupies an important place in the study of the molecular structure of chemical compounds, allowing to establish the nature of atomic groups, their content, the content of functional groups, to clarify the nature of hydrogen bonds and much more. This method was used to assess the effect of fillers of iron oxide nanoparticles on the structural features of PA 6. The choice of iron oxide nanoparticles as a filler was determined by both its strength characteristics and the expected affinity for polyamides. The use of dispersed fillers helps to improve some characteristics of polymeric materials, in particular tribological ones, but, in most cases, reduces the strength properties of composite materials, which imposes significant restrictions on the areas of application of products. But the introduction of nanoparticles can significantly change their properties. The development and technology of manufacturing samples of a nanocomposite based on polyamide are described in [1-14].

According to the IR data, the features of intermolecular interaction of components in the composite are estimated. Usually, the vibration frequency of the molecules of functional groups of the initial materials is observed in the following frequency range, cm<sup>-1</sup>:

-adipic acid  $\nu$  (R-COOH) = ~1760,  $\nu$  (C=O) = 1320-1210,  $\nu_s$  (COO<sup>-</sup>) = 1400-1300,  $\nu_{as}$  (COO<sup>-</sup>) = 1650-1550,  $\delta$  (OH) = 1440-1395 Fig. 1.

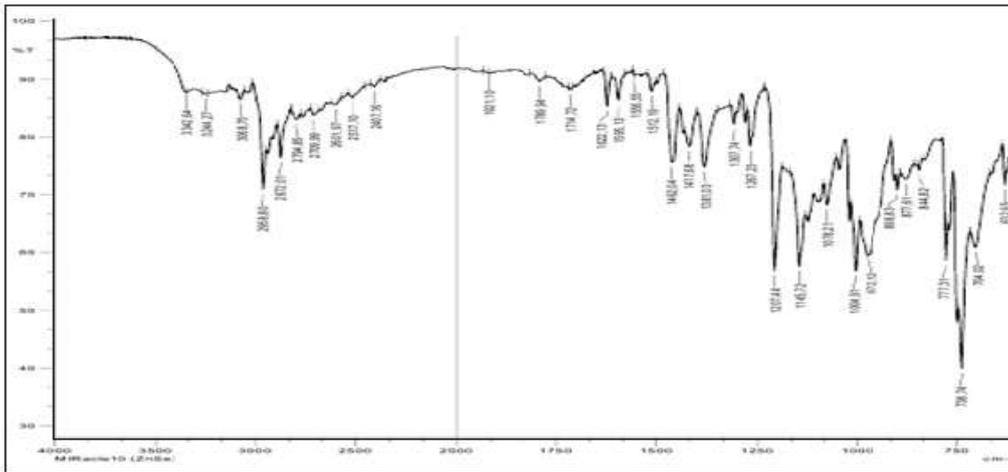


Fig. 1. IR spectra of adipic acid

1,2-diaminohexamethylene:  $\nu_{as}(\text{R-NH}_2)=3500$ ,  $\nu_s(\text{R-NH}_2)=3300$ ,  $\nu(\text{CN})=1600-1500$ ;  
 (Fig. 2)

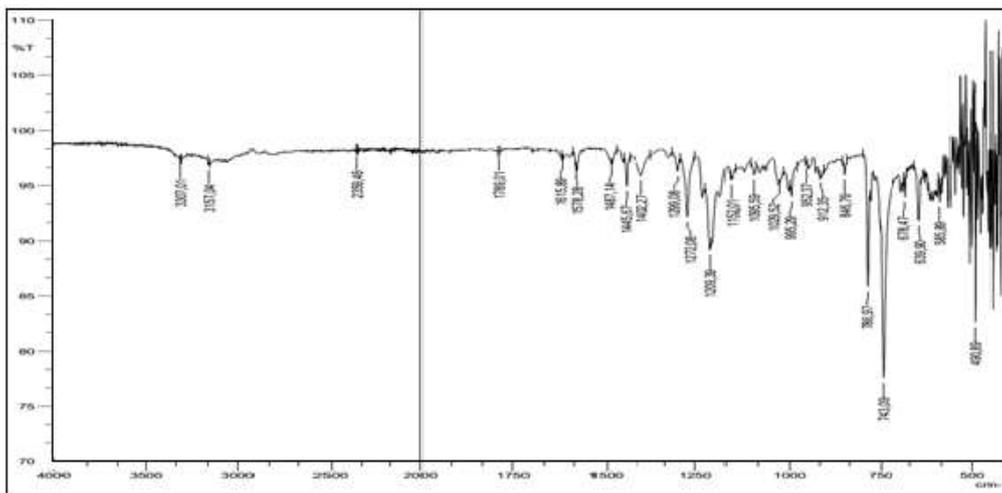


Fig. 2. IR spectra of 1,2-diaminohexamethylene

Polyamide:  $\nu_{as}(-\text{CH}_2-)=2940-2915$ ,  $\nu_s(-\text{CH}_2-)=2870-2845$ ,  $\delta(-\text{CH}_2-)=1480-1440$ ,  $\nu(\text{C=O})=1800-1700$ ,  $\nu(\text{NH})=1670-1630$ ,  $\delta(-\text{NC=O})=2200-2100$ ,  $\delta(\text{CN})=1100-1000$  (Fig. 3).

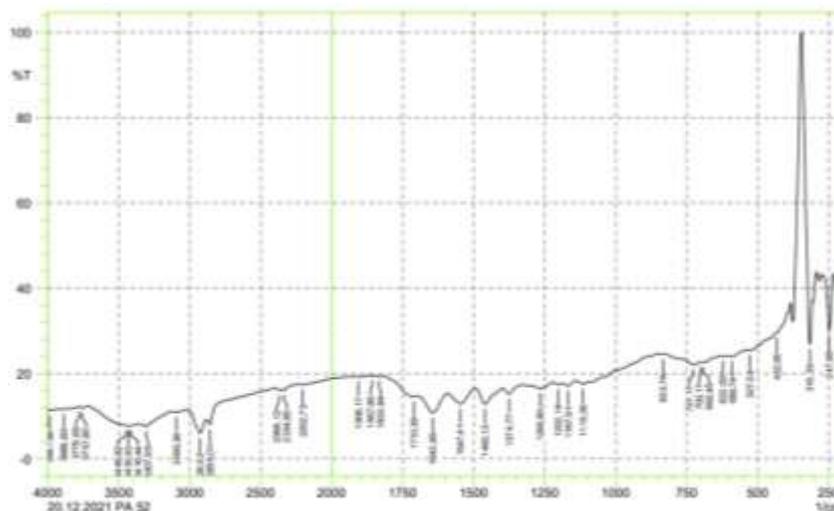


Fig - 3 . IR spectra of pure polyamide

These frequencies are related to compounds of exact chemical composition without additional inclusions. In the spectrum of polyamide-6, additional impurity spectral peaks can be found (Fig. 3).

As is known [4,11,13], phenylones belong to the class of aromatic heat-resistant polyamides and are linear heterochain polymers, the macromolecules of which are built from aromatic fragments of various structures, connected by amide bonds. The presence in the spectrum of polyamide of wide strong bands with a fine weak structure in the region of 3600–2700  $\text{cm}^{-1}$  in both pure, Figure 3 , and metal-filled ( Figure 4-6 ) samples, indicates the presence of delocalized  $\pi$ -electron cloud and intra- and intermolecular hydrogen bonds between amide groups

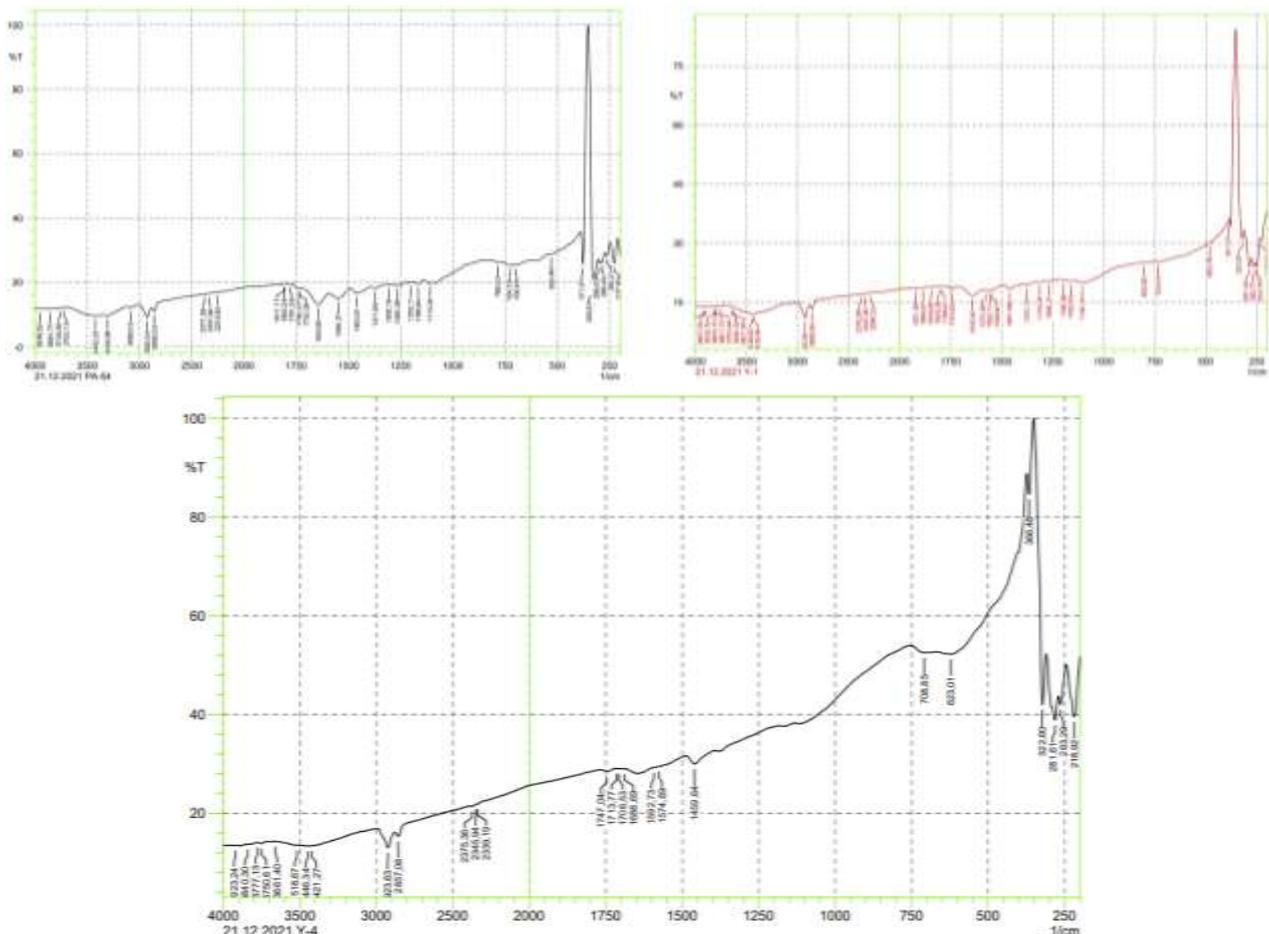


Fig . 6. IR spectra of a composition based on polyamide filled with iron nanoparticles (PA+60% Fe O)

In the spectrum of the polyamide, the bands of NH stretching vibrations (a broad band with a maximum at about 3300–3450  $\text{cm}^{-1}$  ), Amide-I (a split band with maxima at 1643  $\text{cm}^{-1}$ ), Amide - II (also split, 1547–1572  $\text{cm}^{-1}$ ) and Amide-III (a band at 1250–1260  $\text{cm}^{-1}$ ) are clearly identified . In the composition based on phenylone with iron oxide nanoparticles, there is a narrowing and an increase in the intensity of this band with the appearance of a maximum ~at 3420 -3430  $\text{cm}^{-1}$ , which may indicate an increase in intermolecular hydrogen bonds, ordering of the structure due to spatially separated separately meta- and para-amide fragments (splitting is observed in the “ Amide II ” bands (  $\delta(\text{NH})$  associates . 1547 – 1572  $\text{cm}^{-1}$  ) and the

“Amide V” band (700 and 727  $\text{cm}^{-1}$ ) It is possible that the maximum at 3450 -3300  $\text{cm}^{-1}$  is associated with the unchanged structure of the amide group: CONHCN OH since the “Amide II” band disappears at the same time.  $\delta(\text{NH})=15\ 48\ \text{cm}^{-1}$ , associated with deformation vibrations of the free NH group in amide bonds.

Analysis of the IR spectrum of the nanocomposite based on polyamide filled with iron oxide nanoparticles, Figures 4-5, showed the following. A broad strong band in the region of 3700-2500  $\text{cm}^{-1}$  characterizes the presence of delocalized  $\pi$ -electron cloud. There is a fine, weak structure (3 421, 29 23, 2 857), indicating both the intermolecular hydrogen bond between the amide groups and the electrostatic interaction of the quartered nitrogens immonium (by type  $\text{R NH}_2 \oplus \text{RC NH}_2 \oplus$  and carboxylate ions (carbonate, sulfate).

The presence of a wide strong band with a fine structure at 1750-1 4 50  $\text{cm}^{-1}$  additionally testifies in favor of the presence of the  $\text{R}_2\text{C}=\text{NH}$  ( $\delta(\text{NH})$ ,  $\nu(\text{CN})$ ) group, which takes part in the extended conjugation system. Peaks  $\nu_1 = 17\ 4\ 7\ \text{cm}^{-1}$ ;  $\nu_2 = 1\ 459\ \text{cm}^{-1}$  and  $\nu = 70\ 8\ \text{cm}^{-1}$  indicate the presence of imide cycles (bands, respectively, “Imide -I”, “Imide -II”, “Imide -III”). But the presence of the “immonium band” at 16 88  $\text{cm}^{-1}$ , as well as a shoulder on the “Imide -I” band (17 14  $\text{cm}^{-1}$ ), absorptions at 16 88  $\text{cm}^{-1}$  ( $\nu_{\text{as}}-\text{RCO}_2$ ), 14 59  $\text{cm}^{-1}$  ( $2-\text{CO}_3$  or  $\nu(\text{C-N})$  in amides), 12 68  $\text{cm}^{-1}$  ( $\nu(\text{C-N})$  in amides) indicate the presence of “defects” in cyclization, i.e. in the formation of imide cycles - not fully cyclized and, apparently, containing adsorbed  $\text{CO}_2$  ( $2-\text{CO}_3$ ,  $-\text{HCO}_3$ ) groups or  $-\text{SO}_2$  ( $-\text{SO}_3\text{H}$ ) -by the acid residues as anhydride bonds.

It was found that there is no water in the sample, since there is no absorption in the region of 3710  $\text{cm}^{-1}$ . As a result of the studies, it was found that in the IR spectrum of the composite, interaction occurs both through “defective” non-cycled imide cycles and on the imide cycles themselves. Analyzing figures 4-5, we can conclude that bands appear at 168.8  $\text{cm}^{-1}$  in the composite sample, which indicates the formation of a carboxyl group from the former imide group in the arylamide fiber. The disappearance of the band at 14.60  $\text{cm}^{-1}$  ( $\nu(\text{CN})$  in amides) indicates the interaction of uncyclized  $\text{C}=\text{N}$ - groups in the arylamide with the amide and terminal amino groups of phenylone, since this reduces the concentration of hydrogen bonds (region 3300-3900  $\text{cm}^{-1}$ ) and the intensity of the Amide-II band ( $\delta(\text{NH})$ ), associated with vibrations of the associated hydrogen bond of the NH group (region 13.75  $\text{cm}^{-1}$ , 15.49  $\text{cm}^{-1}$ ). Thus, changes in the spectrum of phenylone (an increase in the intensity of the 1076  $\text{cm}^{-1}$  band and the appearance of a weak 1280  $\text{cm}^{-1}$  band) as a result of pressing indicate a decrease in the degree of ordering in the polymer structure, and also, possibly, additional deformation of the chains (the formation of folded structures).

The absence of these features in the spectrum of the composite can be interpreted as a result of the influence of the filler, which somehow prevents the mentioned structural changes. Interpretation of the spectra of the original phenylone and composites based on it, containing iron oxide nanoparticles, allows us to conclude that intermolecular hydrogen bonds of amide groups in phenylone are disrupted and that the fiber interacts with the matrix at the molecular level [5].

Polyamide 6 is a polymer whose structure has been relatively well studied. Like other aliphatic polyamides, it can crystallize in several crystalline modifications, among which the

most stable are  $\delta$  and  $\gamma$ . The modification  $\alpha$  is built from almost completely elongated flat zigzag macromolecules, connected to each other by hydrogen bonds.

The study and analysis of the wave numbers of the absorption bands of the spectra of PA 6 and the composite (60 % Fe O) (Fig. 6) shows that in the region of hydrogen stretching vibrations there are four peaks characteristic of PA 6 – 3315  $\text{cm}^{-1}$ , 3090  $\text{cm}^{-1}$  (stretching vibrations of N–H groups bound by hydrogen bonds) and 2936  $\text{cm}^{-1}$ , 2873  $\text{cm}^{-1}$  (stretching vibrations of CH<sub>2</sub>). The band 3315  $\text{cm}^{-1}$  is broadened due to the superposition of the moisture absorption band and the stretching vibrations of the terminal primary amino groups. The bands 1647  $\text{cm}^{-1}$  and 1551  $\text{cm}^{-1}$  relate to the vibrations of Amide I and Amide II, respectively. The bands are noticeably split; a superposition of the band of deformation vibrations of the terminal –NH<sub>2</sub> groups can be assumed as a possible cause of the splitting. The presence of a weak component at 1665  $\text{cm}^{-1}$  in the Amide I band was mentioned earlier by the authors of [6] without discussing its nature. The Amide III band has two components: a stronger one at 1264  $\text{cm}^{-1}$  and a weaker one at 1203  $\text{cm}^{-1}$ , which is typical of  $\alpha$  the polymer form [6]. The Amide V and Amide VI bands are structurally dependent and in the spectrum we obtained have a position typical of  $\alpha$  the -form of PA 6 - 697  $\text{cm}^{-1}$  and 583  $\text{cm}^{-1}$ , respectively. The fact that pure polyamide is in the crystalline state and in  $\alpha$  the -modification is also indicated by the typical poorly resolved group of bands at 1410 – 1470  $\text{cm}^{-1}$  and the characteristic shape of the 1264  $\text{cm}^{-1}$  band. The spectrum of polyamide 6 we obtained is practically identical to the spectrum of this polymer in the crystalline  $\alpha$ -modification described in the literature [6, 7]. The spectra of composites with 15 and 30 mass. % of filler differs little from the spectrum of pure PA 6 [8]. One can only note a change in the contour of the 1264  $\text{cm}^{-1}$  band (the intensity of the low-frequency shoulder has increased), an increase in the peak of 733  $\text{cm}^{-1}$  due to the superposition of the 718  $\text{cm}^{-1}$  band arimide, as well as the appearance of weak peaks at 823  $\text{cm}^{-1}$  and 886  $\text{cm}^{-1}$ . The absorption of arimide -T in composites is somewhat different from the absorption of pure fiber. Differences are noticeable in the region of stretching vibrations of hydrogen atoms, indicating a change in the nature and number of hydrogen bonds, which, in turn, is caused by the interaction between the matrix and the fiber. The interaction of the polymer and the filler can also explain changes in the spectrum region of 1660 - 1300  $\text{cm}^{-1}$ .

As for the nature of the above-mentioned interaction, it may include both redistribution of hydrogen bonds and chemical interaction of non-cyclized regions of poly-N, N-bis( phenoxyphenyl ) pyromellitimide with terminal amino and carboxyl groups of polyamide. Purely electrostatic interactions of charged functional groups – carboxylate ions and ammonium – are also possible. The consequence of such interaction is homogenization of the composite. The spectrum of the composite containing 45 wt. % of filler has significant differences compared to the two previous ones and to the spectrum of pure PA 6. First of all, fiber bands are clearly visible (shoulders 1780  $\text{cm}^{-1}$  and 1726  $\text{cm}^{-1}$  on the Amide I band, 1086  $\text{cm}^{-1}$ , 702  $\text{cm}^{-1}$ ). The peaks of 1035  $\text{cm}^{-1}$  (due to the overlap of the band 1352  $\text{cm}^{-1}$  iron) and 817  $\text{cm}^{-1}$  (due to the overlap of the band 796  $\text{cm}^{-1}$  iron) increase significantly. In addition, the spectrum of this composite has features that allow us to conclude that with an increase in the filler content to 40%, changes occur in the matrix structure. This reasoning is supported by the results of additional studies to determine the filler concentration in polyamide using ultraviolet spectroscopy based on the Bouguer -Lambert- Beer law. (Fig. 7).

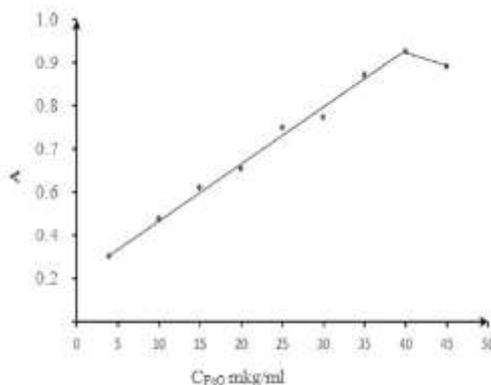


Fig. 7. Dependence of optical density on filler concentration according to the Bouguer-Lambert-Burr law.

Thus, the Amide V band merges with the  $718\text{ cm}^{-1}$  band of iron and is observed at  $700\text{ cm}^{-1}$ , and the Amide VI band shifts toward high frequencies and is observed at  $600\text{ cm}^{-1}$ . The intensity of the bands in the region of  $1000 - 1100\text{ cm}^{-1}$  increases significantly. All of the listed features allow us to conclude that, with a fiber content of 40 wt. %, PA 6 in the composite either forms an amorphous phase or is in  $\gamma$ the -form (these states, according to [6], are difficult to distinguish). (Fig. 8) It should be noted that the spectrum of this composite contains a fairly strong band at  $1503\text{ cm}^{-1}$ , which is absent in the spectra of both modifications of PA 6 and in the spectrum of the fiber. The appearance of this band, in our opinion, indicates the formation of double bonds  $C = N$  and  $N = N$  (cis -position), that is, partial decyclization and destruction of the arimid -T structure. Comparative analysis [8, 9, 10] of the IR spectra of PA 6, iron and composites based on them shows that there are interactions between the polymer matrix and the filler, in which non-cyclized sections of the fiber polymer and the terminal carboxyl and amino groups of PA 6 participate. Interactions can include the formation of hydrogen bonds, chemical interactions and electrostatic interactions. The consequence of chemical interactions is the enolization of carbonyl groups of non-cyclized sections of cis -addition of polyamide molecules, which leads to a change in the structure of PA 6 and its amorphization with an increase in the filler content to 40 wt.%.

## CONCLUSION

In a composition based on phenylone with iron oxide nanoparticles, there is a narrowing and strengthening of the intensity of this band with the appearance of a maximum ~at  $3420 - 3430\text{ cm}^{-1}$ , which may indicate the strengthening of intermolecular hydrogen bonds, ordering of the structure due to spatially separated meta- and para-amide fragments.

IR spectra of PA 6 + FeO showed that there are interactions between the polymer matrix and the filler, in which non-cyclized sections of the fiber polymer and the terminal carboxyl and amino groups of PA 6 participate.

The consequence of chemical interactions is the enolization of carbonyl groups of non-cyclized sections of cis -addition of polyamide molecules, which leads to a change in the structure of PA 6 and its amorphization with an increase in the filler content to 40 wt. %.

These findings provide clear spectroscopic evidence that the incorporation of iron oxide nanoparticles leads not only to physical embedding within the polymer matrix but also to chemical interaction at the interface. The shift and intensification of the N-H and C=O vibrational bands suggest the reorganization of hydrogen-bonding networks, which is typically

associated with modifications in supramolecular architecture. The observed amorphization with increasing nanoparticle content indicates a disruption of the crystalline domains and partial replacement of ordered regions with disordered interphase structures.

Such structural modifications are consistent with previously reported mechanisms of filler-induced polymer reorganization, where the presence of surface-active metal oxides promotes changes in chain mobility, packing density, and hydrogen-bond distribution. As the filler content approaches 30–40 wt.%, the polymer transitions into a predominantly heterogeneous composite in which the degree of crystallinity decreases, while interfacial interactions intensify. This correlates with the emergence of broadened amorphous halos and the attenuation of diffraction peaks observed in complementary X-ray diffraction studies.

In addition, the enolization of carbonyl groups implies the possible occurrence of localized electron density redistribution and partial proton transfer, which may facilitate supramolecular stabilization through donor–acceptor interactions. The interaction of iron oxide nanoparticles with terminal functional groups suggests the formation of coordination-type bonds or dipole–dipole interactions, which further reinforce the hydrogen-bonding system.

From the standpoint of material performance, such structural rearrangements can influence key functional properties, including thermal stability, mechanical strength, wear resistance, and dimensional stability. The partial amorphization of PA 6 combined with strengthened interfacial interactions may lead to increased toughness and reduced brittleness, while the disruption of crystalline domains may enhance the diffusion of stress and energy dissipation under load.

Overall, the obtained results confirm that controlled incorporation of FeO nanoparticles into polyamide-based matrices can serve as an effective method for targeted structural modification. The identified spectroscopic changes support the feasibility of designing polymer composites with tunable supramolecular organization, which is essential for optimizing their application in mechanical engineering components operating under dynamic and thermal stress.

#### **Adabiyotlar/Литература/References:**

1. Wehrenberg , R. New composites expand actions for processors /R. Wehrenberg // *Plastics World*. – 1985. –Vol.5. – p. 39–43.
2. F. T. Baimuratov , U. Abdurakhmanov , G. Yu. Yurkov , Umarov AV, Local Energy of Activation of Conductivity of Phenylene-Based Composite Materials Containing Nickel Nanoparticles, *Journal of Polymer and Textile Engineering (IOSR-JPTE)* e-ISSN: 2348-019X, p-ISSN: 2348-0181, Volume 7 , Issue 2 (Mar. - Apr. 2020), PP 01-09 [www.iosrjournals.org](http://www.iosrjournals.org) , DOI: 10.9790/019X-07020109
3. Umarov, AV, Abdurakhmanov, U. , Khamzayev, HE , Kattaev, NT , Tozhiboev, AG , Synthesis and Structural Investigations of Metal-Containing Nanocomposites Based on Polyethylene // *Zeitschrift fur Naturforschung - Section A Journal of Physical Sciences* Volume 74, Issue 3, 1 March 2019, Pages 183-187. DOI : <https://doi.org/10.1515/zna-2018-0332> .
4. Sokolov, L.B. Heat-resistant and high-strength polymeric materials / L.B. Sokolov. - M.: Knowledge, 1984. - 64 p.

5. Arimid fiber on IR spectroscopic characteristics of phenylone / A.I. Burya, E.V. Tkachenko, S.P. Suchilina-Sokolenko [et al.] // Questions of Chemistry and Chemical Technology. - 2007. - No. 4. - P. 68-72.
6. S.Yu. Khashirova, M.B. Begova, A.T. Tsurova, et al. Structure and properties of composites based on polyamide-6 and modified organoclay, *Plastics*, No. 1-2, 2019, pp. 40-43.
7. James L. Dwyer and Ming Zhou, Polymer Characterization by Combined Chromatography-Infrared Spectroscopy, *International Journal of Spectroscopy* Volume 2011, Article ID 694645, 13 pages doi:10.1155/2011/694645.
8. Burya, A.I. IR spectra and structure of composites based on polyamide-6 filled with Arimid / A.I. Burya, A.S. Redchuk, E.V. Tkachenko [et al.] // Questions of Chemistry and Chemical Technology. - 2010. - No. 1. - P. 67-70.
9. Patent 2193186 Russian Federation, IPC G01N25/02 Method for determining the glass transition temperature of polymer films, including photoresist films / Churikov A.A.; patent holder Voronezh State University No. 2000115401/28; declared 14.06.2000; published 20.11.2002 - Electronic version oven publ.- Access mode: <http://www.findpatent.ru/patent/219/2193186.html>.
10. James L. Dwyer and Ming Zhou, Polymer Characterization by Combined Chromatography-Infrared Spectroscopy, *International Journal of Spectroscopy* Volume 2011, Article ID 694645, 13 pages doi:10.1155
11. Umarov AV, Kurbanov M, Xusniddinov FSh, Abdullaeva BS, Mansurova MY. Study and analysis of the IR spectra of a composition based on polyamide filled with iron nanoparticless. *E3S Web of Conferences* 401, 05085 (2023). <https://doi.org/10.1051/e3sconf/202340105085>
12. Paul DR, Robeson LM. Polymer nanotechnology: Nanocomposites. *Polymer*. 2008;49(15):3187-3204.
13. Mittal V. Polyamide nanocomposites: synthesis, characterization and applications. Wiley; 2011.
14. Alexandre M, Dubois P. Polymer-layered silicate nanocomposites. *Mater Sci Eng R Rep*. 2000;28(1-2):1-63.
15. Seydibeyoğlu MÖ, Mohanty AK. Nanoclay reinforced polymer composites. Springer; 2014.
16. Liu T, Phang IY, Shen L, Chow SY, Zhang W-D. Morphology and properties of polyamide 6/layered-silicate nanocomposites. *Polym Int*. 2004;53(8):1164-1170.
17. Pérez E, Cerrada ML. Crystalline structure of polyamide 6. *Macromolecules*. 2003;36(4):1378-1385.
18. Pegoretti A, Kolarik J. Friction and wear behaviour of polyamide composites. *Wear*. 2000;237(1):110-117.
19. Jagtap RN, Thorat SD. IR spectral analysis of polyamide nanocomposites. *J Appl Polym Sci*. 2016;133(22):43461.
20. Kocsis JK, Thomann R, Schulte K. Thermoplastic nanocomposites for structural applications. *Compos Sci Technol*. 2002;62(10-11):151-160.
21. John MJ, Thomas S. Biofibres and biocomposites. *Carbohydr Polym*. 2008;71(3):343-364.
22. Mohd Ishak ZA, Senawi R. Nanoparticle-filled polyamides. *J Thermoplast Compos Mater*. 2000;13(4):345-359.
23. Pielichowski K, Njuguna J. Thermal properties of polymer nanocomposites. Springer; 2005.

24. Oliveira M, Torres F, Ferreira J. Processing of polymer nanocomposites. *Polym Test*. 2010;29(7):833-840.
25. Zhang Q, Yu Z-Z. Nanofiller effects on PA6 structure. *J Mater Sci*. 2005;40(16):4321-4328.
26. Sinha Ray S, Okamoto M. Polymer/layered silicate nanocomposites. *Prog Polym Sci*. 2003;28(11):1539-1641.
27. Prolongo SG, Masegosa RM. Metal-polymer nanocomposites. *J Mater Sci*. 2012;47(12):4501-4513.
28. Song Y, Zheng Q. Interaction in polymer/oxide nanocomposites. *Polymer*. 2009;50(19):4887-4895.
29. Wang Z, Pinnavaia TJ. Clay-reinforced polymer composites. *Chem Mater*. 1998;10(12):3769-3771.
30. Kim HS, Lee BH. Tribological PA6 nanocomposites. *Wear*. 2011;270(1-2):158-164.
31. Carotenuto G, Nicolais L. Metal-polymer nanostructures. *Adv Mater*. 2003;15(10):829-834.
32. Mittal G, Dhand V. Review of polymer nanocomposites. *Macromol Mater Eng*. 2016;301(1):9-38.
33. Wetzel B, Hauptert F. Impact of nanoparticles on polymers. *Compos Sci Technol*. 2003;63(15):2055-2067.
34. Shen L, Chow SY. Polyamide crystallinity studies. *Polym Int*. 2000;49(9):937-944.
35. Sachse S, Döring M. Spectroscopic analysis of polyamide composites. *Vib Spectrosc*. 2013;65:88-95.
36. Hsieh AJ, Yang J-M. Structural polymer nanocomposites. *Compos A Appl Sci Manuf*. 2006;37(12):1901-1926.

**YANGI DAVR ILM-FANI: INSON UCHUN  
INNOVATSION G'OYA VA YECHIMLAR**  
**II RESPUBLIKA ILMIY-AMALIY KONFERENSIYASI MATERIALLARI**  
2026-yil, yanvar

**Mas'ul muharrir:** *F.T.Isanova*  
**Texnik muharrir:** *N.Bahodirova*  
**Diszayner:** *I.Abdihakimov*

**Yangi davr ilm-fani: inson uchun innovatsion g'oya va yechimlar.**  
II Respublika ilmiy-amaliy konferensiyasi materiallari to'plami.  
2-jild, 2-son (yanvar, 2026-yil). – 343 bet.

Mazkur nashr ommaviy axborot vositasi sifatida 2025-yil, 8-iyulda  
C-5669862 son bilan rasman davlat ro'yaxatidan o'tkazilgan.

**ISSN:** 3093-8791 (onlayn)

**Elektron nashr:** <https://konferensiyalar.com>

**Konferensiya tashkilotchisi:** "Scienceproblems Team" MChJ

**Konferensiya o'tkazilgan sana:** 2026-yil, 22-yanvar

**Barcha huquqlar himoyalangan.**  
© Science problems team, 2026-yil.  
© Mualliflar jamoasi, 2026-yil.