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APPLICATION OF FOURIER TRANSFORM INFRARED SPECTROSCOPY (FTIR) IN SAMPLE PREPARATION: MATERIAL CHARACTERIZATION AND MECHANISM INVESTIGATION

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ABSTRACT

Fourier Transform Infrared Spectroscopy (FTIR) is an instrumental analysis technique that is widely used in the fields of materials science, engineering, and microbiology. The principle of FTIR is based on molecular vibrations that produce a characteristic spectrum as a “molecular fingerprint.” In sample preparation, FTIR plays an important role in material characterization (solid sorbents, metal organic frameworks, hybrid materials) and investigation of the extraction mechanisms of organic, inorganic, and biomacromolecular molecules. This study used a quantitative descriptive approach with observation, interviews, and documentation at the Analytical Chemistry Laboratory of the Lhokseumawe State Polytechnic. The results show that FTIR is most effective in the field of materials science (85%), followed by microbiology and the environment (80%), and least effective in asphalt and materials engineering (75%). With its speed, non-destructive nature, and flexibility, FTIR has great potential, although the interpretation of complex spectra remains a major challenge.

Keywords: FTIR, material characterization, sample preparation, extraction mechanism, bioremediation

1. INTRODUCTION

1.1 Background

Sample preparation is one of the most crucial stages in laboratory analysis, as errors or inaccuracies at this stage can produce biased data and reduce the validity of the analysis results (Zhao et al., 2023). As analytical science advances, various instrumental methods are used to ensure accuracy and efficiency in sample processing. One technique that is growing in popularity is Fourier Transform Infrared Spectroscopy (FTIR) (Mohamad & Sapawe, 2024).

FTIR works by measuring the absorption of infrared radiation by molecules based on the vibration and rotation of their chemical bonds. The resulting spectrum represents a unique pattern of specific functional groups, so it can be used for identification, characterization, and quantification. Since the 1970s, FTIR has been widely used in food analysis, pharmaceuticals, materials science, and biomedicine (Yudaev et al., 2025).

In the context of materials science, FTIR is widely used to verify the success of synthesizing solid sorbents, molecularly imprinted polymers (MIPs), metal-organic frameworks (MOFs), and hybrid materials (Sutton et al., 2024). FTIR is capable of detecting specific functional groups, assessing the stability of materials under extreme pH conditions and radiation, and confirming the presence of new chemical bonds (Affiku et al., 2024).

In civil engineering, FTIR is used to monitor asphalt quality and its aging process. Modification of asphalt with polymers or other additives can be monitored through FTIR spectra, particularly changes in the intensity of carbonyl absorption bands, which are closely related to chemical degradation due to oxidation (Lee, 2024).

Meanwhile, in microbiology and the environment, FTIR is applied for rapid identification of microorganisms, biofilm analysis, and bioremediation monitoring (Ahsan et al., 2024). Changes in the FTIR spectrum of carboxylate, amine, and protein groups can be used as indicators of microbial interactions with organic pollutants and heavy metals (Haskaj et al., 2024).

This article aims to present a systematic review of the application of FTIR in sample preparation, with a focus on material characterization and investigation of extraction mechanisms, while evaluating its advantages, limitations, and development prospects.

2. RESEARCH METHODS

2.1 Research Design

This study uses a quantitative descriptive approach to describe the role of FTIR in sample preparation through observation, interviews, and documentation in the laboratory.

2.2 Research Location and Time

The research was conducted at the Analytical Chemistry Laboratory of Lhokseumawe State Polytechnic from January to April 2025.

2.3 Population and Sample

The research population consists of all laboratory users, namely practicum students, lecturers, and technicians. Total sampling technique was used so that all users present became respondents.

2.4 Research Instruments

The research instruments consisted of an observation checklist and a literature review sheet, covering:

1. FTIR applications in material characterization
2. FTIR applications in asphalt analysis
3. FTIR applications in microbiology and bioremediation
4. Advantages and limitations of FTIR
5. Effectiveness score of FTIR application.

2.5 Data Collection Techniques

1. 1) Direct observation of FTIR use in the Analytical Chemistry Laboratory.
2. 2) Structured interviews with lecturers and laboratory technicians.
3. 3) Documentation in the form of photographs of facilities, instruments, and sample preparation procedures.

2.6 Data Analysis Techniques

Data was analyzed descriptively and quantitatively using the percentage of effectiveness in each field (material science, asphalt, microbiology & environment). The results were presented in tables, graphs, and narrative descriptions.

3. RESULTS AND DISCUSSION

3.1 Research Results

Based on observations in the Analytical Chemistry Laboratory, data on the application of FTIR in each field was obtained.

Table 3.1 FTIR application data in each field

Application Field	Focus of Analysis	Advantages of FTIR	Challenges	Effectiveness Score (%)
Ilmu Material (MIP, MOF, COF)	Material characterization, functional group verification, stability	Fast, non-destructive, detects specific function groups	Interpretation of complex spectra	85
Asphalt & Engineering Materials	Modifier blending, asphalt aging analysis	Monitoring chemical changes, the ATR method is more practical	Solvent interference, low sensitivity for complex mixtures	75
Microbiology & Environment	Microbial identification, biofilm, bioreme	Rapid microbial identification, ecosystem monitorin	Overlapping spectrum, requires integrati	80

diation	g	on of other techniqu es

3.2 Discussion

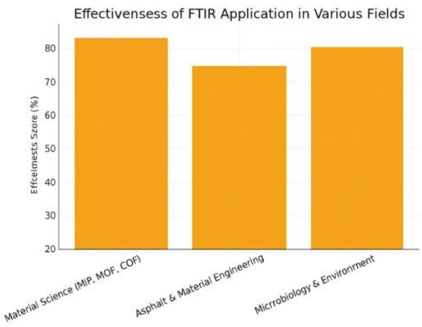

Figure 3.1 Graph showing the application of FTIR in each field.

The analysis results show that the effectiveness of FTIR use varies in each field of application, although in general this technique contributes greatly to sample preparation.

The field of material science has the highest effectiveness (85%). This is because FTIR has high sensitivity in identifying chemical functional groups in solid sorbent materials such as molecularly imprinted polymers (MIPs), metal-organic frameworks (MOFs), and hybrid materials. FTIR spectra can confirm the successful synthesis of materials through specific vibration peaks, for example, in carbonyl, hydroxyl, or amine groups.

Another advantage is that FTIR can be used to evaluate the stability of materials against radiation or extreme pH conditions, which is relevant for selective separation applications. However, spectrum interpretation can sometimes be complicated due to overlapping absorption bands, requiring database support or advanced statistical analysis.

In engineering materials, especially asphalt, FTIR plays an important role in analyzing the mixing process of modifiers and monitoring material aging. Asphalt aging is usually caused by the oxidation of organic components, which can be detected through changes in carbonyl or sulfhydryl functional groups. The use of ATR-FTIR (Attenuated Total Reflection) is preferred over transmission because it is simpler and can be applied directly to solid asphalt samples.

However, its effectiveness is relatively lower (75%) due to limitations such as solvent interference and low sensitivity in analyzing complex mixtures. This indicates the need to develop more consistent sample preparation methods to improve the accuracy of the analysis results.

In the fields of microbiology and the environment, FTIR is very useful for microbe identification, biofilm analysis, and bioremediation of organic pollutants and metals. FTIR spectra can provide a "molecular fingerprint" for each microorganism, so it can be used as a rapid method for diagnosing infections or monitoring ecosystems.

In the context of bioremediation, changes in the intensity of absorption bands in carboxylate, phosphate, or protein groups can indicate the mechanism of interaction between microbes and pollutants. Its effectiveness is quite high (80%), but the main limitation is spectrum overlap, which makes the identification of certain microbes difficult. Therefore, integrating FTIR with other methods (e.g., DNA sequencing or mass spectroscopy) is highly recommended.

Overall, FTIR has proven to be a versatile, fast, non-destructive technique with a wide range of applications. However, its effectiveness is greatly influenced by the type of sample, preparation method, and availability of spectral databases. The biggest challenges are the complexity of data interpretation and limitations in analyzing heterogeneous mixed samples.

4. CONCLUSION

4.1 Conclusion

Based on the results of the research that has been carried out, the following conclusions can be drawn:

1. FTIR plays an important role in sample preparation, with its main functions being material characterization, material degradation monitoring, and microbe identification.
2. The field of material science shows the highest effectiveness (85%), followed by microbiology & environment (80%), and asphalt & engineering (75%).
3. FTIR offers advantages such as speed, non-destructive testing, and application flexibility, but faces challenges in interpreting complex spectra.

4.2 Suggestions

1. There is a need to develop an FTIR spectrum database to accelerate and improve identification accuracy.
2. It is recommended that FTIR be integrated with AI/machine learning to address the complexity of spectra in heterogeneous samples.
3. Interdisciplinary research needs to be expanded so that FTIR can support more fields of application.

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