ANTIBACTERIAL FURAN DERIVATIVES: A RAMAN SPECTROSCOPIC INVESTIGATION

N.B. Saidkarimova[1], A.N. Yunuskhodjaev[2], M.R. Karimova[3]
Tashkent Pharmaceutical Institute[1]
Institute of Pharmaceutical Education and Research[2]
https://doi.org/10.5281/zenodo.16935281

Abstract. *In this research, Raman spectroscopic analysis was conducted on widely used antibacterial drugs containing a furan ring — furacilin (nitrofural), furadonin (nitrofurantoin), and furazolidone. The spectra were recorded and analyzed using the R-532 Raman spectrometer. Characteristic peaks associated with the furan ring and nitro groups were identified, and spectral differences among the compounds were highlighted. This study demonstrates the effectiveness of Raman spectroscopy in distinguishing structurally similar pharmaceutical substances, particularly furan derivatives, and underscores its utility for compound identification and quality control of drug products.*

Keywords: *raman spectroscopy; furan derivatives; antibacterial drugs; furacilin; furadonin; furazolidone; spectral identification.*

Introduction

The furan ring is a five-membered aromatic heterocycle possessing a conjugated π-electron system involving an oxygen atom. Its derivatives, including furfural, furfuryl alcohol, 5-hydroxymethylfurfural, and others, occur in natural sources and often constitute the fundamental structural framework of pharmaceuticals. Therefore, elucidating the structural features of these molecules is of great importance for understanding their chemical properties and pharmacological activity.

Although the furan molecule has a relatively simple structure, obtaining precise information about its atomic arrangement, electron density, and isotopic composition enables an in-depth analysis of its structure, physicochemical properties, and the relationships with its derivatives. The determination of accurate geometric parameters is achieved through the study of vibrational and rotational motions of the molecules.

This objective can be achieved using one of the modern spectroscopic techniques—Raman spectroscopy. In addition to providing highly accurate information, this method allows non-destructive analysis, meaning that the integrity of the substance remains intact. As a non-invasive and rapid technique for studying the molecular structure of compounds, it is particularly effective for π-electron system–containing derivatives such as those of furan.

Organic compounds containing the furan ring—such as furacilin (nitrofural), furadonin (nitrofurantoin), and furazolidone—are widely used antibacterial drugs with strong activity against various bacteria. These substances belong to the class of nitrofurans, and their pharmacological effects, biological stability, and chemical reactivity are directly related to the furan ring and the functional groups attached to it. Therefore, analyzing the structural features of these compounds at the molecular level represents an important and relevant task.

According to the regulatory documents for these three drugs, their authenticity is determined by a color reaction characteristic of the nitro group, which produces a color ranging

from yellow-red to dark brown upon treatment with alkali. Alternatively, in the UV-spectrophotometric method, solutions prepared in dimethylformamide exhibit absorption maxima at 375 ± 2 nm for furacilin and at 367 ± 2 nm for both furadonin and furazolidone within the 250–450 nm range. However, these methods require considerable time and the use of organic solvents, while also posing difficulties in distinguishing the drugs from one another. In this respect, Raman spectroscopy offers significant advantages, being rapid, requiring no sample preparation, and providing unique vibrational peaks for each functional group.

Vibrational modes of the C=C, $–NO_2$, C–N, N–N, and C–H bonds in furan derivatives can lead to significant variations in their electronic structure, conformational states, and isomeric forms. These differences may, in turn, influence the physicochemical properties of the drugs, including solubility, metabolic stability, and biological activity. Therefore, detailed investigation of these compounds using high-precision spectroscopic methods is of both scientific and practical importance.

The aim of this study is to investigate the spectral properties of furan-derived drugs such as furacilin, furadonin, and furazolidone using Raman spectroscopy, to identify their characteristic vibrational peaks, and to evaluate the potential of these data for drug identification and quality control.

Experimental Section. The spectra were recorded using the R-532 Raman spectrometer manufactured by Enhanced Spectroscopy (USA). The technical specifications of the instrument are as follows: spectral range 100–6000 cm^{-1}, spectral resolution 5–8 cm^{-1}, laser wavelength 532 nm, output power 50 mW, linear CCD detector with 3648 pixels, focal length 75 mm, entrance slit 20 μm, and holographic grating with 1800 lines/mm.

Initially, the Raman spectrum of furacilin was examined. A band at 1020 cm^{-1} was attributed to C–O–C stretching vibrations of the five-membered heterocyclic ring involving the oxygen atom. Peaks at around 1328 and 1346 cm^{-1} were characteristic of the $–NO_2$ group attached to the aromatic ring, corresponding to its symmetric and asymmetric stretching vibrations, respectively. Additionally, bands at 1184 and 1198 cm^{-1}, as well as a medium-intensity band at 1250 cm^{-1}, were assigned to C–O stretching. The most intense band in the spectrum, observed at 1469 cm^{-1}, was associated with the N–N bond of the semicarbazide fragment of the furacilin molecule. Meanwhile, C=C stretching vibrations of the aromatic ring were observed at 1594 cm^{-1} (Figure 1).

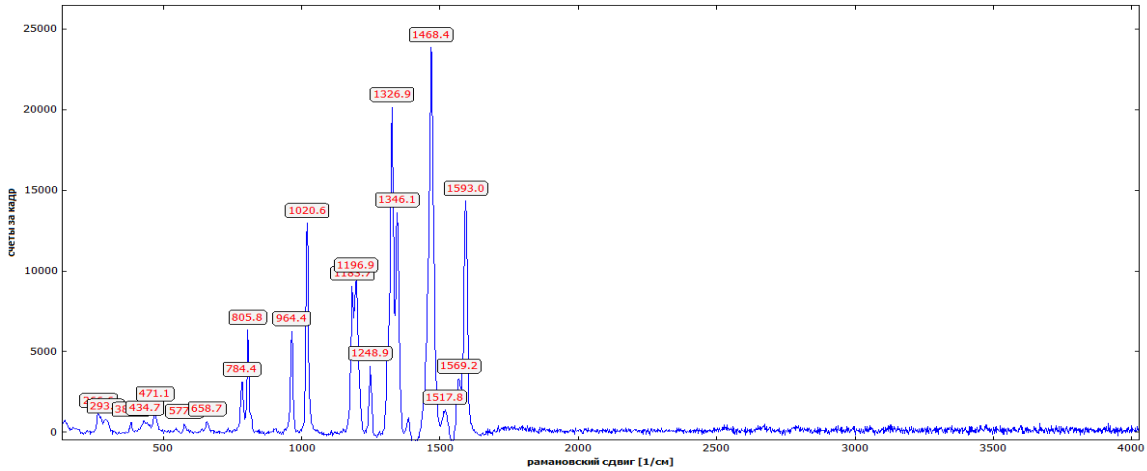

Figure 1. Raman spectrum of the furacilin drug substance

Subsequently, the Raman spectrum of the furacilin tablet was also studied, and its scattering bands were found to correspond to the characteristic peaks observed in the spectrum of the pure drug substance (Figure 2).

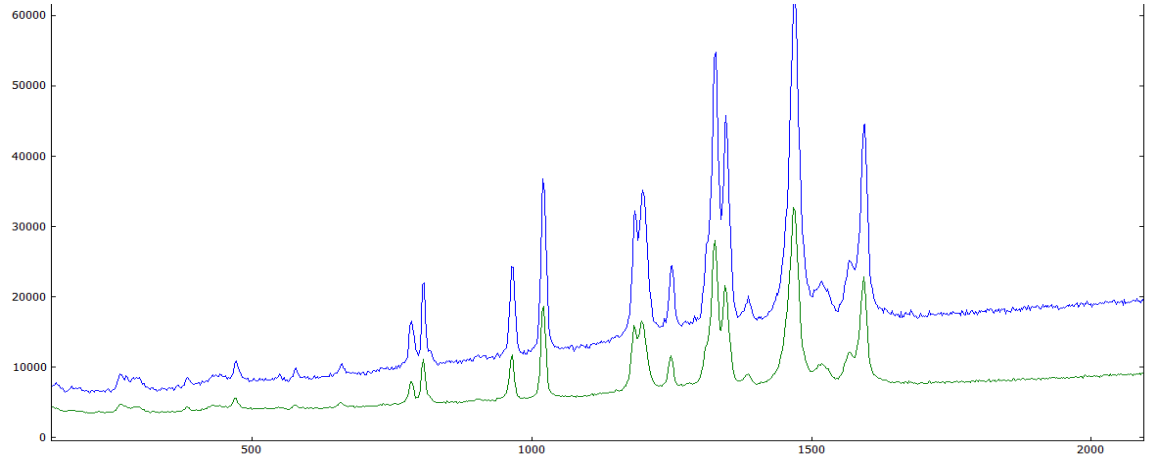

Figure 2. Raman spectra of furacilin drug substance and tablet

In the Raman spectrum of furadonin, peaks observed at approximately 1019, 1342, and 1377 cm^{-1} indicated the C–O–C stretching vibrations of the heterocyclic ring and the presence of the nitro group. Additionally, the bands at 1172 and 1248 cm^{-1} were attributed to C–O stretching vibrations. Similar to furacilin, furadonin also contains an N–N bond, which appeared at 1493 cm^{-1}. Unlike furacilin, however, furadonin exhibited strong peaks at 1607 cm^{-1} corresponding to C=O stretching vibrations in its hydantoin moiety, which were identified as characteristic for furadonin (Figure 3).

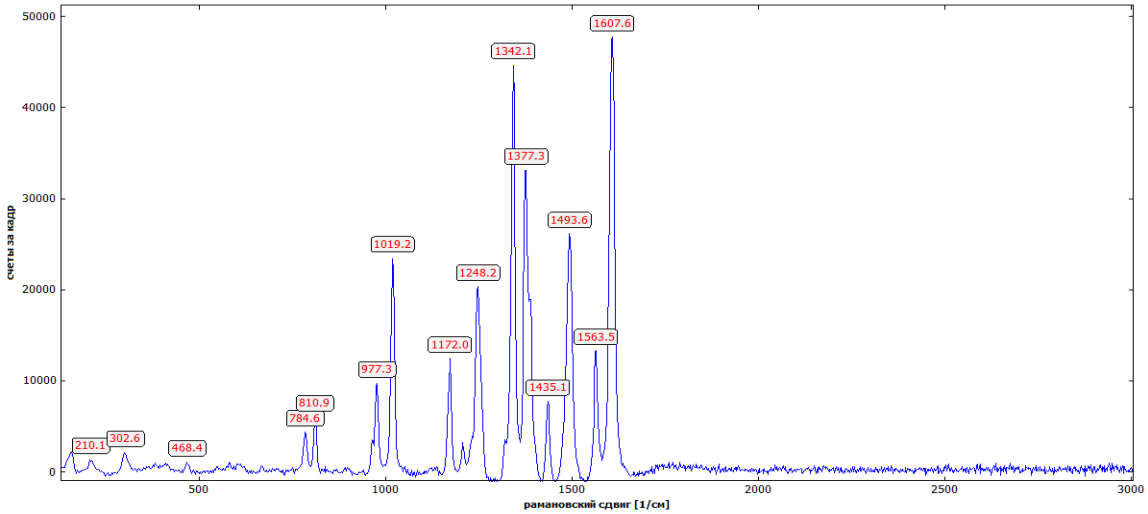

Figure 3. Raman spectrum of the furadonin tablet

The Raman spectrum of furazolidone, which is structurally similar to furadonin, was also studied and found to exhibit a high degree of similarity. Characteristic peaks were observed at 1020, 1170, 1341, and 1375 cm^{-1}. Unlike furadonin, however, furazolidone contains an aminooxazolidone ring instead of the aminoglydantoin fragment, and additional scattering bands at 1235 and 1254 cm^{-1} were attributed to C–O vibrations involving the oxygen atom within the ring. These were considered distinctive vibrational modes useful for differentiating the molecules. Furthermore, intense peaks corresponding to C=O stretching vibrations were detected at 1611 cm^{1} (Figure 4).

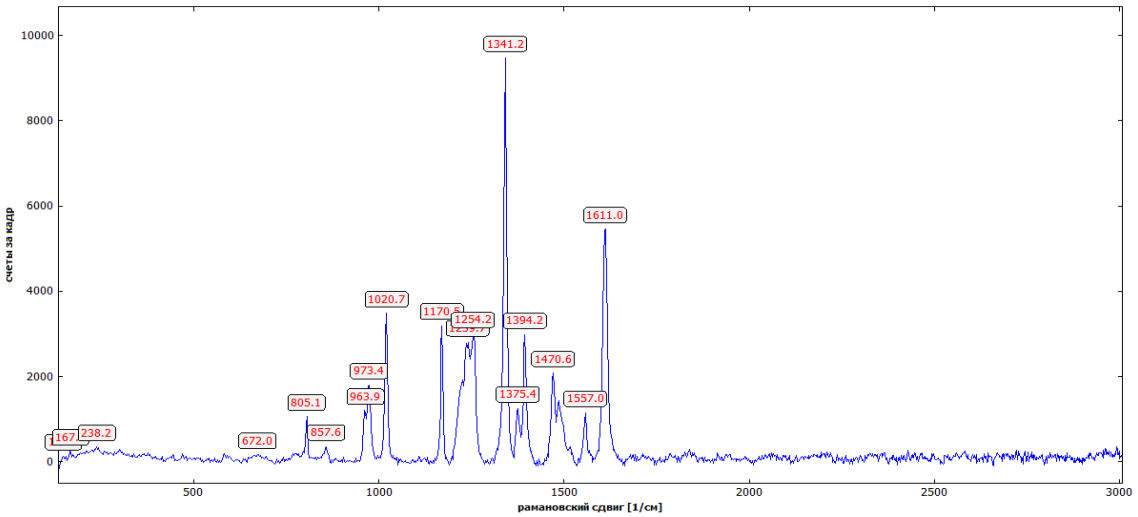

Figure 4. Raman spectrum of the furazolidone drug substance

The Raman spectrum of the furazolidone tablet was also obtained and compared with that of the pure drug substance, revealing that its scattering bands corresponded well with those of the active compound (Figure 5).

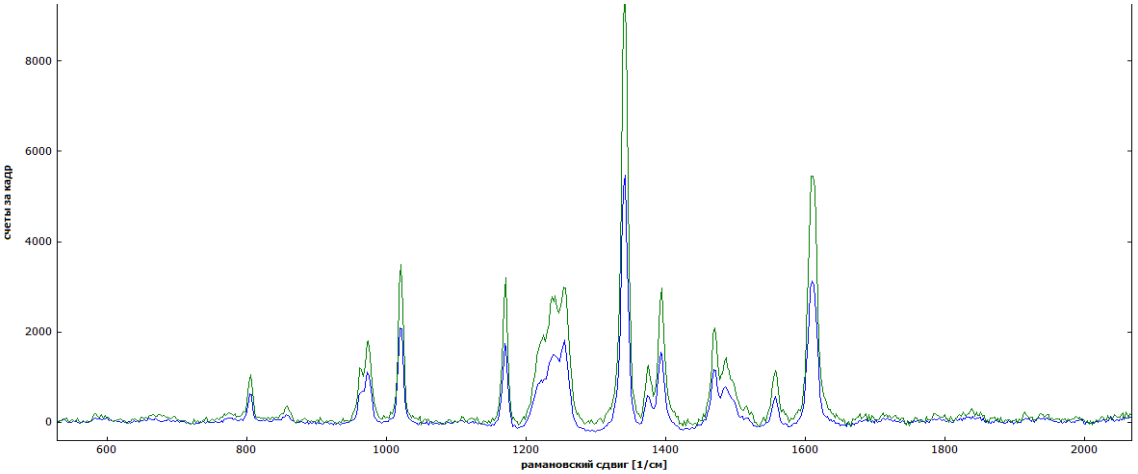

Figure 5. Raman spectra of furazolidone drug substance and tablet

Conclusion

In this study, Raman spectroscopic analysis of the furan-containing drugs furacilin, furadonin, and furazolidone was carried out. The results demonstrated that the main functional groups of these compounds can be identified and differentiated through their characteristic vibrational peaks.

The bands at 1020 cm^{-1} and within the 1325–1375 cm^{-1} range were common to all three compounds, corresponding to C–O–C vibrations of the furan ring and the symmetric and asymmetric stretching vibrations of the $–NO_2$ group. In contrast, the carbonyl group (C=O) produced characteristic peaks at 1607 cm^{-1} for furadonin and 1611 cm^{-1} for furazolidone, which were absent in furacilin. Furthermore, the Raman spectra of the tablet dosage forms were studied and found to correspond closely with those of the pure substances. These findings confirm that Raman spectroscopy is an effective and reliable analytical technique for drug identification, structural characterization in pharmaceutical dosage forms, and quality control.

REFERENCES

1. Averheim A., Thyrel M. Raman spectroscopy for the quantification of furans in blow steam condensates derived from steam explosion of softwood bark //Biomass Conversion and Biorefinery. – 2025. – T. 15. – №. 11. – p. 17369-17378.
2. Kim T. et al. Vibrational properties of levulinic acid and furan derivatives: Raman spectroscopy and theoretical calculations //Journal of Raman spectroscopy. – 2011. – T. 42. – №. 12. – p. 2069-2076.
3. Mirzayeva M., Saidkarimova N., Yunuskhodjaev A. A RAMAN SPECTROSCOPY STUDY OF ALKALOIDS IN THE PLANT VINCA ERECTA //Science and innovation. – 2024. – T. 3. – №. D9. – p. 47-51.
4. Nigmanovich Y. A. et al. Development of a Topical Curcumin Gel for Skin Burn Regeneration //International journal of pharmaceutical compounding. – 2024. – T. 28. – №. 6. – p. 530-535.
5. Považanec F. et al. Furan derivatives. CVI. Infrared, ultraviolet, and Raman spectra of substituted 5-phenyl-2-furonitiiles //Chem. zvesti. – 1978. – T. 32. – №. 3. – p. 392-396.
6. Saidkarimova N., Yunuskhodjaev A. Using Raman Spectroscopy to Investigate Drugs with Similar Chemical Structures and Antagonistic Effects. Latin American Journal of Pharmacy. -2024. №. 43.10: 2251-5.
7. Temirov J. B., Saidkarimova N. B., Abdijalilova Z. Kh. Assessment of the quality of saffron syrup extract by Raman spectroscopy // Scientific-Practical Conference on Modern Achievements and Prospects in Pharmaceutical Technology. -2024. №.4(2), 313–314. https://doi.org/10.5281/zenodo.10683397
8. Thuriot-Roukos J. et al. Raman spectroscopy applied to monitor furfural liquid-phase oxidation catalyzed by supported gold nanoparticles //ACS omega. – 2020. – T. 5. – №. 24. – p. 14283-14290.
9. Wan F. et al. Charge transfer effect on Raman and surface enhanced Raman spectroscopy of furfural molecules //Nanomaterials. – 2017. – T. 7. – №. 8. – p. 210.