The possibility of total protein concentration determination based on acoustojet phenomenon

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Abstract. It is well known that it is possible to convert sound speeds in blood into corresponding densities and total protein concentrations. In this paper we numerically study the possibilities of the blood characteristics and total protein concentrations determinations based on acoustojet phenomenon. It has been shown that the particle of the blood immersed in water allow to form acoustical field localization near the shadow surface of particle by illumination of ultrasound.

1. Motivation
The concentration of the red blood cells and of the blood proteins is of general interest to the physician [1-3].

A method which extended the concentration measurement to the continuous evaluation of haematocrit and total protein concentration was successfully introduced for the investigation of body fluid dynamics in Refs. [4, 5]. The method was based on the continuous measurement of blood density.

Also a method was introduced for monitoring the concentration of blood constituents in perfused and disposable polymer tubes [6]. The method is based upon the measurement of the sound speed (v), because of it is possible to convert sound speeds in blood into corresponding densities and total protein concentrations.

It is well known that the sound speed in blood is closely related to total protein concentration as well as to the haematocrit [7-9].

Total protein concentration is the sum of the plasma protein concentration \( C_{\text{plasma}} \) and of the mean cellular haemoglobin concentration (MCHC) weighted by the volume fraction of the component [10]:

\[ TPC = \text{MCHC} \cdot \text{hct} + c_{\text{plasma}} \cdot (1 - \text{hct}), \]

where TPC = total protein concentration, hct = haematocrit.

From the optical band it is well known now the phenomenon of photonic nanojet [11], allow to form localized light in subwavelength area by scattering of light on low loss dielectric particle. Photonic nanojets effect have motivated us to propos the concept of acoustic jets, called “acoustojet” [12].

Recently, it has been theoretically demonstrated for the first time [12-13] that an existence of acoustic analogue of photonic jet phenomenon [11], providing for subwavelength localization of
acoustic field in shadow area of arbitrary 3D penetrable mesoscale particle, is possible. It is important to note that the principle difference between optical and acoustical materials properties is a shear speed of sound, i.e. acoustic materials are anisotropic due to the two speed of sound [14].

In this short communication, we show that it is possible to determine the blood parameters based on acoustojet phenomenon.

The scattering of sound from a spherical fluid obstacle of size comparable to a wavelength was considered in [15, 16]. It has been shown that the amplitude of the scattered wave in the backward direction from a fluid sphere a few wavelengths in diameter exceeds twice that from a rigid sphere of the same size for the case of the relative sound velocity 0.8 and density equal to that of the surrounding medium [16]. Focusing effect in the sound scattering by a spherical balloon with high diameter filled with carbon dioxide was investigated in [17, 18].

In our analysis of acoustojets [12-14], in simulations we use the rigorous partial-wave expansion method [14, 19-20], which depends on the beam-shape and scattering coefficients, to obtain the scattered pressure around the solid elastic spherical particle, where both compressional and shear waves were taken into account.

2. Results of investigation
Let’s briefly consider the influence of water temperature to the main characteristic of acoustojet by spherical particle. In the Table 1 the sound velocity (V) and density of water (Rho) vs temperature is shown [21].

| T, C | V, m/s | Rho, g/cm³ |
|------|--------|-----------|
| 10   | 1445   | 0.9997    |
| 20   | 1490   | 0.9982    |
| 50   | 1556   | 0.988     |
| 80   | 1557   | 0.9718    |

Water density as a function of temperature only is given by [22]:

\[ Rho = 1000(1 - (T+288.9414)/(508929.2*(T+68.12963))*(T-3.9863)^2) \]  \( \text{(2)} \)

Water density as a function of temperature and salinity is given by [22]:

\[ Rhos = \rho + AS + BS^{3/2} + CS^2 \]  \( \text{(3)} \)

where \( A = 8.24493 \times 10^{-1} - 4.0899 \times 10^{-3} \times T + 7.6438 \times 10^{-5} \times T^2 - 8.2467 \times 10^{-7} \times T^3 + 5.3675 \times 10^{-9} \times T^4 \), \( B = -5.724 \times 10^{-3} + 1.0227 \times 10^{-4} \times T - 1.6546 \times 10^{-6} \times T^2 \), \( C = 4.8314 \times 10^{-4} \), \( Rhos = \text{density in kg/m}^3 \) as a function of temperature and salinity, \( S = \text{salinity in g/kg} \).

In ref. [10] the sound speed and the density of a series of blood samples was measured in a temperature range from 20 °C to 40 °C and is shown in Table 2.

| Sound velocity, m/s | 1570 ... 1595 |
|---------------------|----------------|
| Density, kg/m³      | 1050 ... 1055  |
| Attenuation, dB/cm²MHz⁻¹ | 0.15 ... 0.22 |
| Viscosity, mPa/s    | 1.7 .... 4.4   |

Below in the Figure 1 the acoustojet at different water temperature are shown for the blood sphere of 8λ diameter.
3. Conclusion

We have demonstrated that acoustojet (acoustic jets) formed from acoustic plane wave scattering by spheres of a blood with diameter of several wavelengths may be used for subwavelength localization of acoustical wave. This phenomenon is similar to photonic nanojets in electromagnetic waveband. However, in the scattering by elastic solid particles, shear waves is produced within the scatterer due to mode conversion. This is a principal difference between acoustojet and photonic nanojet and reduces the intensity of acoustojets.

This mesoscale particles may be considered as an acoustic superlenses with resolution beyond the diffraction limit and thus due to subwavelength resolution and high energy gradient may be used for medical diagnostics, for example, for total protein concentrations.

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Figure 1. Acoustojets from blood sphere immersed in water with different temperature.

The simulations shown that an increase in the water temperature leads to an insignificant change in the length of the acoustojet and slightly increase sidelobes (shown by arrow).

In the Figure 2 the focusing effect from the blood sphere immersed in water is shown for ultrasound wave. It can be seen the acoustojet form in the shadow surface of the blood’s particle.

Figure 2. Pressure distribution under the ultrasound scattering on blood spherical particle immersed in water. Particle diameter is $4\lambda$.

Thus it is possible to determinate total protein concentration [10] of blood particle immersed in water.
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