Ocean Rheology and Ian R. Jenkinson

Plankton Biology

Agency for Consultation and Research in Oceanography, Hydrosphere Biorheology Laboratory, 19320 La Roche Canillac, France

1. Introduction

The mechanical properties of the air, the land and natural waters (the hydrosphere) determine the nature and the rates of most processes in our environment. The rheology of the hydrosphere is largely determined by natural products produced by organisms. Ocean Rheology, part of Hydrosphere Rheology is thus a part both of Biorheology and of Environmental Rheology.

4. Effect of Organic Matter on Rheological properties

Supporting data are sparse, it is thought that organic matter modifies Type A.1 rheology (Box 2) only slightly (<<1%) [1], although further studies on changes in attenuation (viscosity-related) and velocity (elasticity-related) of sound in relation to colloidal organic matter would be desirable.

For **Type A.3 rheology**, existing methods appear too insensitive to allow changes in extensional viscosity to be detected.

2. Types of Rheology

A. 3-D rheology of the bulk phase: 1) Bulk (volume-compression) rheology of the bulk phase; 2) shearing rheology of the bulk phase; 3) extensional rheology of the bulk phase.

B. 3-D rheology of bulk material extracted from films: E.g. 3-D shearing rheology of material extracted from the air-water film.

C. 2-D rheology: 1) Extension-compression rheology of films (sometimes accompanied by electrochemical measurements), notably of the air-water film; 2) 2D-shearing rheology of surface films, notably the air-water film.

D. 1-D rheology: Just one kind, 1-D rheology of string-like structures.

3. 3-D Volume-Compression ("Bulk Rheology") of the Bulk Phase (Type A.1 Rheology). Alemán [1] have reviewed volume compression rheology of ocean water in respect to molecular structure, and parametrised it in terms of temperature, salinity and hydrostatic pressure (depth). They furthermore discussed the possible influence of dissolved and particulate organic matter particularly on viscosity.

Since sound consists of compression waves, the bulk rheological properties are the basis for acoustics in the hydrosphere.

Values for the density of seawater as a function of salinity, temperature and hydrostatic pressure are well known [2], and some values are given in Table 1, along with values of compression-flow elastic modulus G'_{k} derived thus:

 $G'_{k} = (P_{1} - P_{0}) / \{(\rho_{1} - \rho_{0}) / [(\rho_{1} + \rho_{0})/2]\}$

(1)

For rheology of Types A.2, B, C.1 and C.2, either viscosity or elasticity or both can be considerably increased by polymeric organic matter (OM) excreted by phytoplankton [3,4,6,11,12,17,19,20,21,23] Bacteria and some zooplankton may also contribute.

While different types of OM probably contribute to this thickening, the dominant material for thickening both the surface film and the bulk phase is acid polysaccharides, often complexed with proteins and/or lipids.

In **Type A.2 rheology**, phytoplankton OM typically adds a highly shear-thinning component to the Newtonian solvent viscosity, the solvent being "pure" seawater (water and inorganic salts). When sufficiently marked and shear-thinning, this can produce a yield stress [8,9].

Type A.2 rheology (and probably that of **A.3**, but this is difficult to measure in such a dilute medium) is distributed in a patchy way [11,12], probably more or less associated with lumps or aggregates of polymer[16]. Formation of lumps and patches is poorly understood, but is undoubtedly due partly to flocculation, partly to differential sedimentation of aggregates leading to collisions, and partly due to biological formation [11,12,16].

Types A.2 and A.3 rheology, particularly for shear-thinning materials and at the low shearing deformation and extensional deformation rates, both 10⁻⁶ to 1 s⁻¹, characteristic of the ocean interior, can increase total viscosity by several orders of magnitude over solution viscosity. As measured so far, the elastic modulus is generally < 20% of the excess viscous modulus (that part due to polymers). Such increases in viscosity must markedly change the properties of small-scale ocean turbulence. However, partly because turbulence is still difficult to characterise, such changes have so far eluded experimental observation.

where P_0 and P_1 are two values of hydrostatic pressure, and ρ_0 and ρ_1 are the the corresponding values of density

Values of G'_{ν} range from 3.5 x 10¹⁰ to 4.5 x 10¹⁰ Pa for most values of salinity, temperature and hydrostatic pressure found in the oceans.

TABLE 1. Density ρ (kg.m⁻³) as a function of salinity S (practical salinity units), temperature t (°C), hydrostatic pressure P (Pa) and compression-flow elastic modulus G'_{k} (Pa). (P = 0 means atmospheric pressure)

S	t	Ρ	ho	G ' _k
0	5	0	0.99996675	
		10 ⁸	1.04412802	4.32 x 10 ¹⁰
	25	0	0.99704796	
		10 ⁸	1.03790204	4.01 x 10 ¹⁰
35	5	0	1.02767547	
		10 ⁸	1.06948914	3.99 x 10 ¹⁰
	25	0	1.02334306	
35	5 25	10 ⁻ 10 ⁸ 0	1.02767547 1.06948914 1.02334306	4.01 × 10 ¹⁰ 3.99 × 10 ¹⁰

Type B rheology Shearing rheology of bulk material taken from the surface film by means of a glass plate, has shown viscous and elastic moduli around 3 times that in water from the underlying layer [6].

Type C.1 rheology. Compression-dilation rheology ("dynamic surface tension") of the surface film has been measured [17,19,20,21,22] using a Langmuir trough, coupled with a Wilhelmy plate suspended perpendicular to and cutting the surface. Such measurements are sometimes coupled with electrochemical measurements of how surface charge varies during the compression-dilation cycle. This complements the surface rheograms in giving information about molecular processes associated with this deformation, and is important for understanding the effecs of surface organic matter in altering ripples in the surface film (propagating through surface-film elasticity) and the bigger gravity waves (Fig. 4).

Type C.2 rheology. This has been little measured and the viscous and elastic moduli are very small compared to correspoong C.1 rheology, but were found to be likewise correlated with phytoplankton abundance and type in the underlying water [23].



Fig. 3. Sketch of the Mark 3 ichthyoviscometer (not to scale) [9]

1.06253817 108

3.76 x 10¹⁰

The compression-flow viscosity η_{κ} of seawater has been deduced (Alemán et al 2005) from values in pure water as a function of hydrostatic pressure P together with knowledge about how shearing viscosity η_s in seawater (measured at high \dot{y} [3]) varies with temperature t and salinity S, and how and elongational viscosity η_{F} of pure water are likely to vary with t, S, P and compression rate \dot{X} . The authors conclude that η_{κ} under ambient oceanic conditions will be positively related to P and t, as well as to compression χ over a range from 0.2 to 1%, but negatively to values of from 10⁹ to 10¹⁰ s⁻¹. Under these ambient conditions η_{κ} will range between 1 and 4 mPa.s, giving a characteristic compression time $T_{\kappa} = \eta_{\kappa}/G'_{\kappa}$ of the order of 4 x 10⁻¹³ s. Sound is composed of compression waves, so sound of frequency << 10¹² Hz will generally propagate with little attenuation. The presence of bubbles and organic matter (OM), however, may greatly reduce values of G'_k , and so increase T_{κ} . Bubbles or OM may also increase η_{κ} , inducing increased acoustic energy dissipation and sound attenuation, with increased diffraction effects including scattering.

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Fig 4. Photograph of surface wake pattern, 100 min after the passage of a Navy ship [25]