Letter from the CIS

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Classification of porous media with through pore channels

A simplified classification of porous media with through pores, which took into account both the structure of the medium and its compressibility (*i.e.* its ability to deform under the action of external forces) was given for example in Reference 1, but in reality there is a much more diverse range of porous media, making it necessary to extend the scope of the classification scheme (Table 1).

As can be seen from the scheme shown, deformable structures can be formed for all types of porous layers with through pores (*i.e.* granular, non-granular or mixed), with their ability to deform being determined by the properties of the materials forming the porous layer, as well as by the type of initial particle packing in this layer.

By deformation we mean here not only the ability of a layer to change its volume, in particular to compress under the action of external forces, but also its ability to change volume and porosity under the effect of stresses occurring in the moving liquid (or gas) as a result of the frictional forces between the flow and the particle surface of the layer (*i.e.* the surface of the pore channel). These effective stresses in the cake (layer) are not distributed uniformly, and increase from the flow's inlet to the channel to its outlet [see Reference 2].

Usually, in hydromechanical processes such as sedimentation, filtration, centrifugation, squeezing and washing, the term 'cake compressibility' is used instead of 'cake deformation'. Cake compressibility means the ability of a cake to reduce its volume (porosity) under compressive stresses occurring in it, resulting in an increase in hydraulic resistance. However, this definition is to be corrected.

The main factors causing cake deformation (in particular compressibility) are as follows:

- ☐ Structural changes in the packing of layer elements.
- ☐ Elastic deformation of boundary adsorption layers of the liquid on the surface of the layer's structural elements.
- ☐ Elastic and plastic deformations of the material/structural elements forming the porous medium.
- ☐ Destruction of the material of the structural elements (particles) in the layer.

This list is incomplete, since it does not comprise all possible causes of cake deformation. However, the list does allow us to systematise them. Porous layer deformations may be elastic or non-elastic (plastic). Various combinations of the above factors offer a complicated deformation pattern of a real pore layer (cake). Of the above causes of pore layer deformation, let us consider only two: elastic deformation of the layer material, and changes in the layer structure.

Depending on the boundary conditions, elastic deformations of the layer material can lead to both compression and expansion of the layer (see Figure 1). If the inner surface of the layer is rigid and immobile, the pore material deforming under the action of a pressure drop and effective stress created by the moving medium will compress the layer (Figure 1*a*). With rigid fixing of the

Table 1. Classification of porous layers with through pores.

Type of layer (porous medium)	Structure	Behaviour	Examples
Granular layers (1)	Rigid particles (point contact)	Non-compressible layers	Sand, quartz etc. (1, 1)
		Compressible (compactible) layers	Compaction due to changes in particle placing (dust etc.); in principle the assumption is valid for all cakes (1, 2)
	Deformable particles (surface contact)	Compressible layers	Polyurethane etc. (1, 3)
Non-granular layers (2)	Rigid skeleton	Non-compressible layers	Ceramics, pored metals (2, 1)
	Deformable skeleton	Compressible layers	Elastic, cellular etc. (2, 2)
			Non-elastic, paste types (2, 3)
Mixed layers (3)	Rigid skeleton and rigid filler particles	Non-compressible layers	Composites of metals and metal ceramics (3, 1)
	Rigid skeleton and deformable filler particles*	Compressible layers	Composites with deformable filler particles (3, 2)
	Deformable skeleton and rigid filler particles	Compressible layers	Nonwoven materials with mineral (granular) filler particles (3, 3)
	Deformable and filler particles	Compressible layers	Nonwoven materials with deformable filler etc. (3, 4)

* The degree of compressibity is determined by the ratio of granules (particles) and skeleton material in the layer. These materials can be conveniently referred to as semi-compressible.

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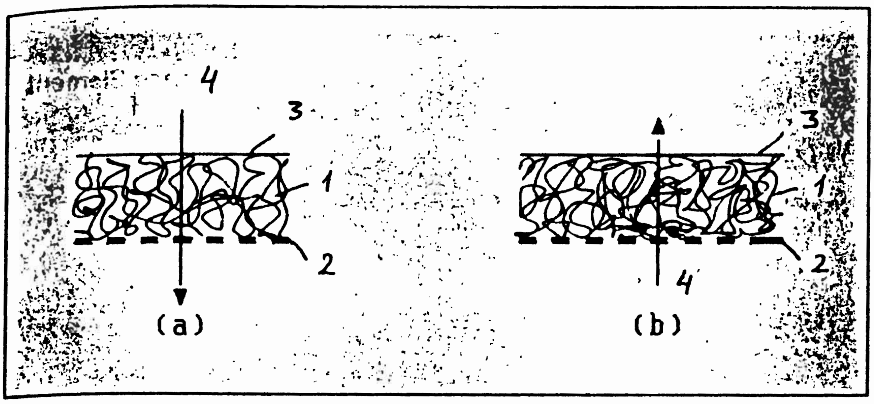

Figure 1. Deformation of a porous material with through pores: (1) Porous material, (2) Rigid immobile porous backing or porous material base, (3) Free surface of the material, (4) Medium movement direction through the porous layer.

frontal layer of the porous material and net structure of the interconnected layer elements the reverse phenomenon is observed, *i.e.* layer expansion (Figure 1*b*). Materials like knitted 'Spandex' may serve as an example.

If layer elements are not bound into a net, and are able to move spatially in the layer, then the porous material can deform by analogy with the scheme in Figure 1. The 'pseudoliquefied' layer (*i.e.* free particle migration in the layer) is the limiting case for upward flow (Figure 1*b*) in the absence of a common net structure for the layer particles.

It is obvious that the pseudoliquefied layer does not belong to the deformable layer, which anticipates a 'skeleton' taking up the load transferred from one particle to another as a result of their contact. However, this approach allows us to introduce media which are deformable by hydromechanical processes into a more general system of expanding porous media, where there is a quantitative transition from an expanding deformable porous medium to a pseudoliquified layer.

An interesting problem for modelling is presented by a combined case: an expanding porous medium with an inner pseudoliquefied phase – a filler.

Structural changes in the porous layer can occur with no change in its total volume, because of redistribution of one of the components of the porous composite layer inside the rigid skeleton of the layer under the action of mass forces or hydrodynamic flow. In this case there is a redistribution of local porosity inside the porous material, as well as changes in the length and configuration of through pores accompanied by a change in the total hydraulic resistance of the layer. In the limiting case of the porous composite layer unbound with the skeleton, we can observe migration of free particles in the skeleton with the flow.

Thus, for hydromechanical processes a deformable porous medium (cake) can be defined as a porous medium with through pores which is capable of changing its volume and/or porosity under the influence of external conditions and hydrodynamic flow, as a result of its redistribution of porous material volume, and as a result its hydraulic resistance (permeability) changes.

A particular example of deformable porous media is compressible porous media (cakes), the porosity of which decreases and/or is redistributed in the porous material volume at the same time as its hydraulic resistance increases under the action of external forces and the force of hydrodynamic flow moving through the porous medium.

Thus expansion of the classification scheme for deformable porous layers formed or used in hydromechanical processes has brought to light a large group of mixed (composite) media, some types of which have not been taken into account in the modelling of deformable cakes or in technological designs. The concept of porous medium deformation in hydromechanical processes of dispersed separation has been extended not only to compressible media, but also to expanding media up to a pseudoliquifying state. A more

Table 2. Types of deformable porous media in hydromechanical processes.

N	Initial state	Flow direction	Deformed state	
1	H	↓	H'	H'<H
2	H	↓	H'	H'=H XX-skeleton ■-filler
3	H	↓ OR ↑	H'	H'=H
4	H	↑	H'	H'=H
5	H	↑	H'	H'>H

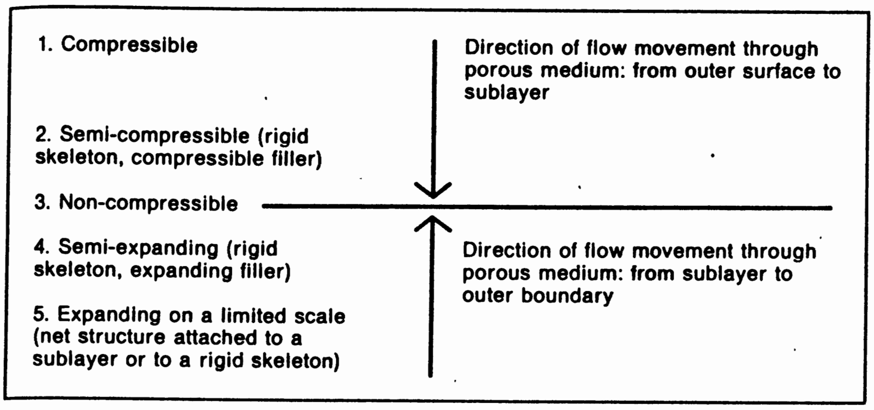

Figure 2. Arrangement of deformable cakes and porous filtration media.

general definition of compressible cakes has been given compared to that in Reference 2, allowing us to include in the cake model those porous media for which an increase in hydraulic resistance is caused not by the change in mean (average) porosity in the volume, but by the redistribution of the solid phase in the medium volume, creating a porosity gradient in it.

On the basis of the above analysis, deformable cakes and porous filtering media can be arranged as shown in Figure 2 (see also Table 2).

Filtration theory and practice have been previously restricted to the analysis and modelling of cakes and porous media of types 1 and 3, although there now exist filter designs which realise filtration using porous media of the other types (*i.e.* 2, 4 and 5) which have the potential for increasing filtration effectiveness.

References

1 Yeh, S.H.: 'Cake deliquoring and radial filtration'. PhD dissertation, University of Houston, Houston, Texas, USA, 1985, p. 283.

2 Zhuzhikov, V.A.: 'Filtration' (Khimiya, Moscow, 1980), p. 400.

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