BIOMEDICAL APPLICATIONS OF MAGNETIC FLUIDS AS A SPECIFIC INTERDISCIPLINARY PROBLEM

1. MAGNETIC FLUID: A SUBSTANCE

The best way to introduce the notion of magnetic fluids in terms of readability and interest towards other than one's own discipline (as the Editor requests) is to start with quotations from the keynote address by Dr. R.E. Rosensweig, whose name is associated with the foundation of the *magnetic fluids* research branch, to the Seventh International Conference on Magnetic Fluids (1995, January):

"It is a fact that only solids that are strongly magnetic are found in nature, not fluids. The strongly magnetic fluids (...) are colloids, most often produced by chemical synthesis. The fluid consists of tiny particles of a magnetic *solid* stably dispersed in a liquid carrier. (...) The particles of magnetite are prevented from sticking to each other by a molecular layer of soap or detergent that coats the surface. In this respect the stabilization of a magnetic fluid has much in common with the technologies of inks, paints and detergents, all of which rely on a molecular surface layer to suspend tiny particles in one liquid to another" [1, p. 3].

"The particles in [magnetic fluids] are minute, only about one-hundred atoms across, and each particle is like a little compass needle suspended in the liquid (...). So when a magnetic field is imposed, the little particles rotate into alignment with the field and the fluid becomes magnetic overall. Unlike a compass needle each particle jiggles around a lot due to the very strong Brownian motion. The motion is essential as it keeps the particles suspended in the liquid instead of settling to the bottom" [1, p. 4].

"It is a curious fact that so far the availability of raw magnetite, soap and solvent is concerned, magnetic fluids could have been synthesized hundreds of years ago but in fact they have been in existence for only about thirty years" [1, p. 3].

2. MAGNETIC FLUIDS: AN INTERDISCIPLINARY RESEARCH BRANCH: SPECULATIONS

The first inventors of magnetic fluids (MF) or, at least, MF precursors were chemists [1, p. 3]. However, only in 1992-95 in the United States special sessions devoted to MF "have appeared spontaneously in the meetings of the ... American Chemical Society ..., American Physical Society ... and Materials Research Society..." [1, p. 2]. There is "a rich specific heritage that underlines the topic of magnetic fluids, representing as it does a unique confluence of the disciplines of electromagnetism *and*

hydrodynamics concerning a complex fluid of interest to colloid science. New combinations of old, unrelated subjects often excite the interest of scientists from the separate disciplines and beyond" [1, p. 5].

The research of magnetic fluids displayed previously unknown phenomena in the fields of hydrodynamics and crystallization [1, p. 7]. Various technological applications of MF are known in different fields of science and technology (e.g., applications in bearings, seals, dampers, devices for heat and mass transfer; in techniques of sink/float separation of minerals, in techniques of separation of gold from alluvial deposits, and grinding of ceramics [1, pp. 6–7]; the unique properties of MF made it possible to use MF-based techniques also in computer devices, aerospace and petroleum technologies [2] etc.). Moreover, just from the formal viewpoint MF research may be considered as originally located at the junction of physics, chemistry, mechanics and material sciences; nowadays, as it follows from some of the above- listed applications, it may be considered also as a part of engineering.

However, to note the interdisciplinary character of the research branch in this way is just *to observe and proclaim, but not to document.* We may document, of course, certain selected patents, articles, R&D reports etc., but what is the guarantee that our examples are representative and unprejudiced? A good aid to support or disprove such observations as those listed above is scientometrics.

3. METHODOLOGICAL APPROACH AND METHODS

Scientometrics is that branch of the Science of Science dealing with quantitative assessment of science indicators (like the number of researchers, amounts of funding to support research activity etc., but mostly the quantity of the scientific documents (articles, reports, books, patents etc.) as the latter is a normal *immediate* formally assessable result of research activity. Scientometrics *does not deal so much with the content* of the indices under assessment. Our idea is that the "obviousness" of the current conclusion of Chapter 2 ought to be supported by documented data, obtained by "mere" scientometric calculations that—though often looking superficial—are never open for prejudice. It goes without saying that scientometric study is also —on a larger scale—used in the present work for investigating the characteristics of *biomedical applications of magnetic fluids as an interdisciplinary problem.* At the same time, analysis of the content of relevant publications is simultaneously used for the same purpose. So, if we reformulate one of the basic questions put by the present Conference as "Do we have to oppose the understanding of science 'within object' (e.g., peer assessments, expert evaluation, prog-

noses made by the specialists of a domain under consideration) against a form of the understanding of science 'beyond object' (e.g., scientometric evaluation from outside a domain under consideration)?", there would not be any need to oppose them to each other, both approaches being applied together.

In scientometrics the level of interdisciplinarity is being assessed, e.g., by means of the disciplinary structure of the main research fulfilled by employees of co-authors, by data on participation of researchers in "non-profile" conferences, by disciplinary structure of cited references, etc. [3]. Although we have some data on the subject structure of the main research fulfilled by the employees of a representative number of MF researchers and producers, the present study is based mostly on the analysis of scientific *documents and references cited in them.*

A usual problem of such studies is an enormously large number of documents to be involved to warrant their representative quantity. Since not all kinds (species) of documents are equally significant, it is a usual practice to include in such studies only selected kinds of them (e.g., papers published in the leading specialized journals or written by the most cited authors from a domain). For the MF research branch that hasn't *any* specialized journal, totally devoted to this subject (as well as the branch itself has not as yet a nomination corresponding to the existing scientific tradition and is being called in the same manner as its subject), the best *formal way* to select the documents to be under study is to use publications from the Proceedings of the International Conferences on Magnetic Fluids (ICMF) [4]. Another reason for this choice is that many MF researchers are involved in other research, too, and a search for the documents according the authors names brings a lot of publications not referring to MF at all [4].

Generally, proceedings of the international scientific conferences seem to be rather a reliable source of documents under study: the so-called "self-regulating mechanisms of science" are supposed to enable the selection of the international scientific events of potentially the most prominent papers devoted to the most prospective trends of a research branch development, while scientific conferences are usually "the first occasion of communicating scientific findings" [5, p. 237]. In the above-cited keynote address by Dr. Rosensweig the assessment of the increase of the domain members' quantity was fulfilled by the count of the attendees of the ICMF [1, p. 2].

In order to estimate the level of interdisciplinarity of MF research in the periods, related to the terms of the Fifth and Sixth International Conferences on MF (ICMF-5 and ICMF-6) being held (1989 and 1992),

we studied the disciplinary structure of the references to journal articles, cited in the corresponding Proceedings. (Citations to journal articles are normally of about 70% of all the citations from any representative sampling; and our case was regulated by the same rule: 74.24% of such citations are in the ICMF-5 and 74.20% in the ICMF-6 Proceedings.) Specialization of the cited journals was identified with the aid of the special headings of the subject categories of the *Science Citation Index* (which is one of the most usual ways of doing it [6], first applied to the MF research branch study in [7]) and, if a cited journal was not reflected there, its specialization was determined either according to the headings of the *Ulrich's International Periodical Directory* or to common sense. Such journals, non-identified with the aid of the *Science Citation Index*, received 6.51% out of all the citations to journal articles in the ICMF-6 Proceedings, while for the ICMF-5 this portion is even smaller. It is important to note that, according to the *Science Citation Index* headings, some journals are related to more than one discipline; in these cases the journal citations were calculated so many times, as many disciplines a journal was related to.

This method was applied to the articles in both Proceedings, specially devoted to biomedical applications of MF. However, since the latter is the main subject of the present research, we also analyzed the content, as well as subject and disciplinary structure of the publications on biomedical applications of MF *themselves*—but not in the format of the articles in the Proceedings, however, but in a format of *abstracts* in the corresponding abstracts compendiums. The latter was chosen as a more representative sampling for studying the characteristics of productivity: not all the abstract authors are asked for submission of a full paper to the Proceedings. On the other hand, references in the abstracts are small in number, optional and occasional; therefore *not* representative for scientometric research.

4. MAGNETIC FLUIDS: AN INTERDISCIPLINARY RESEARCH BRANCH: DOCUMENTED SCIENTOMETRIC DATA

The disciplinary structure of the mentioned references in the whole Proceedings is presented in Table 1. The number of disciplines, presented by the cited journals, has increased from 30 (which is, by itself, an unusually large number of disciplines, cited by such a compact and relatively "young" domain) up to 44 (the increase is 46.90%). It means that, first, MF research is really a highly interdisciplinary one. Further, such an increase is normally interpreted as evidence of the increased use of the

knowledge generated in disciplines other than the research branch under study [6 etc.], while an increased use of such "interdisciplinary information" is believed to be a very strong determinant of the scientific value of results being obtained in the research branch under study [8 etc.]. In any case, the expansion of the thematic scope of the cited scientific literature is believed to be an apparent sign of the progress of scientific development (this viewpoint is reviewed in [9]). Third, the main reflected disciplines and disciplinary groups documented by scientometric investigation are *really* physics, chemistry, mechanics, material sciences and engineering. Fourth, we are pleased to notice that such disciplines, mentioned in Chapter 2, as crystallography, instruments and instrumentation, aerospace engineering and technology, computer applications and cybernetics as well as metallurgy and mining, are featured in Table 1; that means that an ordinary scientometrician with the least knowledge of what MF research is, can document the links of this branch with the disciplines, discussed in Chapter 2.

Moreover, the list of Table 1 is more complete than the one discussed in Chapter 2. Certainly, we are aware about most of the liaisons, mentioned in Table 1, but did not mention them in Chapter 2 because our memory failed... Scientometrics did not. The two approaches of characterizing a research branch— understanding of science 'within object' and a form of the understanding of science 'beyond object' really *ought to be applied together.*

Fifth—and now we are approaching at last to the heart of the matter—there is an enormous increase not only of the number of citations to biological and medical journals, but also—of their disciplinary structures.

5. BIOMEDICAL APPLICATIONS OF MAGNETIC FLUIDS A SUBSTANTIAL DIVISION OF THE RESEARCH BRANCH

Table 2 plots the data on the relative increase or decrease of the portion of citations to the journals in various disciplinary groups in the ICMF-6 Proceedings as compared with the Proceedings of the ICMF-5. By *relative* increase or decrease we mean the alteration *not* in number of citations but in their portion expressed in per cent. Besides 357.45 per cent increase of citations to biological and medical journals, 65.90% of all the disciplines cited in the ICMF-6 Proceedings are biological and medical disciplines, while the part of medical and biological publications in the Proceedings is but 12.87%. In the ICMF-6 Proceedings citations to biological and medical journals have the 4th rank after physics, mechanics, engineering and there are more citations to medical and biological jour-

nals than to that of material sciences and chemistry. Why?—We think that the reason for such strongly increased information links of MF research with biology and medicine may be the increase of development of applications of MF-based techniques in this area. The supposed increase of development of a certain research direction means its important role in the structure of a research branch.

TABLE I

The disciplinary structure of the bibliographic citations to the journals in the Proceedings of the ICMF-5 and ICMF-6

The disciplines presented by the cited journals Disciplinary groups	The quantity of bibliographic citations to the items representing these disciplines in the Proceedings of ICMF-5			ICMF-6		
	a	%	r	a	%	r[1]
Mechanics	122	26.49	1	83	14.09	2
["Physics" group including:]	182	29.49		190	32.26	
Physics	81	17.57	2	107	18.17	1
Physics, Applied	64	13.88	3	47	7.98	4
Physics, Fluids and Plasmas	13	2.82	7	1	0.17	34
Physics, Condensed Matter	12	2.60	9	13	2.21	11
Physics, Atomic, Molecular and Chemical	11	2.38	10	18	3.06	8
Physics, Mathematical	1	0.22	23	4	0.70	20
["Material Sciences" group including:]	57	12.36		74	12.56	
Material Sciences	57	12.36	4	73	12.56	3
Material Sciences, Ceramics	1	0.17	34			
["Chemistry" group including:]	40	8.68		45	7.64	
Chemistry, Physical	30	6.51	6	35	5.94	6
Chemistry	4	0.87	13	7	1.19	14
Chemistry, Applied	3	0.65	14			
Chemistry, Inorganic and Nuclear	1	0.22	23	2	0.34	26
Chemistry, Analytical				1	0.17	43

[1] a is an absolute figure of the magnitude of the index; % is its percent expression; r is the rank of the index magnitude. Blank means the absence of citations to the disciplinary journals in one of the studied Proceedings. The same symbols are used in the rest of the table

["Engineering" group including:]	20	4.35		79	13.41	
Engineering, Mechanical	13	2.82	7	35	5.94	6
Engineering, Chemical	5	1.05	11	7	1.19	14
Engineering	1	0.22	23			
Engineering, Electrical and Electronic	1	0.22	23	41	6.96	5
["Biology and Medical Sciences" group including:]	13	2.82		76	12.90	
Biophysics	5	1.05	11	10	1.70	13
Cardiovascular System	2	0.43	17	6	1.02	16
Hematology	2	0.43	17	4	0.70	20
Immunology	2	0.43	17	15	2.55	9
Gastroenterology	1	0.22	23			
Medicine, General and Internal	1	0.22	23			
Biochemistry and Molecular Biology				2	0.34	26
Radiology and Nuclear Medicine				14	2.38	10
Cytology and Histology				5	0.85	18
Oncology				4	0.70	20
Medicine, Research and Experimental				4	0.70	20
Biology				3	0.51	24
Pharmacology and Pharmacy				2	0.34	26
Biology, Miscellaneous				2	0.34	26
Microbiology				1	0.17	34
Pediatrics				1	0.17	34
Physiology				1	0.17	34
Surgery				1	0.17	34
Multidisciplinary journals	14	3.04	6	12	2.04	12
Acoustics	3	0.65	14			
Crystallography	3	0.65	14	3	0.51	24
Mathematics	2	0.43	17	2	0.34	26
Mathematics, Applied				1	0.17	34
Instruments and Instrumentation	2	0.43	17			
Aerospace Engineering and Technology	1	0.22	23	2	0.34	26
Optics	1	0.22	23	6	1.02	16
Technology: Comprehensive						

Work[2]	1	0.22	23			
Polymer Sciences				5	0.85	18
Energy and Fuels				2	0.34	26
Geosciences				2	0.34	26
Computer Applications and Cybernetics				1	0.17	34
Metallurgy and Mining				1	0.17	34
Meteorology and Atmosphere Sciences				1	0.17	34
Photographic Technology				1	0.17	34
Total disciplinary citations	461			589		

TABLE II

The disciplinary distribution of the bibliographic citations to the journals in the Proceedings of the ICMF-5 and ICMF-6 (only highly cited disciplines and disciplinary groups)

The discipline or disciplinary group	The quantity of bibliographic citations to the items representing these disciplines in the Proceedings of ICMF-5			ICMF-6			Relative increase (+)/decrease (-) in the ICMF-6 Proceedings
	a	%	r	a	%	r	%
"Physics" group	189	39.48	1	190	32.26	1	- 18.29
Mechanics discipline	122	26.46	2	83	14.09	2	- 46.75
"Material Sciences" group	57	12.36	3	74	12.56	5	+ 1.62
"Chemistry" group	40	8.68	4	45	7.64	6	- 11.98
"Engineering" group	20	4.83	5	79	13.41	3	+177.63
"Biology and Medical Sciences" group	13	2.82	6	76	12.90	4	+357.45

6. BIOMEDICAL APPLICATIONS OF MAGNETIC FLUIDS AN INTERDISCIPLINARY RESEARCH PROBLEM: DOCUMENTED SCIENTOMETRIC DATA

The conclusion formulated in the title of the present chapter seems to be obvious and is apparently derivable from the above Table 1. However,

[2] The only discipline name that was taken from the *Ulrich's Periodical International Directory* since a directly corresponding name was not found in the *Science Citation Index*

TABLE III

The disciplinary structure of the bibliographic citations to the journals in the articles on biomedical applications published in the ICMF-6 Proceedings

The disciplines presented by the cited journals	The quantity of bibliographic citations to the items representing these disciplines in the Proceedings of the ICMF-6		
	a	%	*r*
Biochemistry and Molecular Biology	14	14.14	1
Immunology	14	14.14	1
Biophysics	10	10.10	3
Material Sciences	9	9.09	4
Chemistry	5	5.05	5
Hematology	4	4.04	6
Oncology	4	4.04	6
Physic, Applied	4	4.04	6
Radiology and Nuclear Medicine	4	4.04	6
Cytology and Histology	4	4.04	6
Medicine, General and Internal	3	3.03	11
Multidisciplinary journals	3	3.03	11
Chemistry, Inorganic and Nuclear	2	2.02	13
Chemistry, Physical	2	2.02	13
Engineering, Electrical and Electronic	2	2.02	13
Biology	1	1.01	16
Biology, Miscellaneous	1	1.01	16
Cardiovascular System	1	1.01	16
Chemistry, Analytical	1	1.01	16
Chemistry, Physical	1	1.01	16
Crystallography	1	1.01	16
Engineering, Chemical	1	1.01	16
Medicine, Research and Experimental	1	1.01	16
Microbiology	1	1.01	16
Pediatrics	1	1.01	16
Pharmacology and Pharmacy	1	1.01	16
Physics	1	1.01	16
Physics, Condensed Matter	1	1.01	16
Physiology	1	1.01	16
Surgery	1	1.01	16

Table 1 plots the disciplinary structure of references in all the Proceedings articles, not in the ones specially devoted to biomedical applications. If we pass to the latter, we should see that 29 disciplines are presented by the periodicals cited in the papers on biomedical MF applications published in the ICMF-6 Proceedings (Table 3). The increase of the number of disciplines cited in the articles on biomedical MF applications published in the ICMF-6 Proceedings as compared with the ones published in the Proceedings of the ICMF-5 is 222.22% (from 9 to 29 disciplines),

the number of cited biomedical disciplines increased from 6 to 17, and the number of the non-medical ones—from 3 to 12 disciplines. Bearing in mind that the expansion of the thematic scope of the cited scientific literature is believed to be a sign of the progress of scientific development, we dare to suppose that biomedical applications of magnetic fluids is not only a highly interdisciplinary research problem characterized by the recent growth of interdisciplinary level, but also a recently progressing research sub-field. Cf. with the analogous data for the disciplinary structure of citations in the Proceedings on the Second and the Third Symposia on Bone Marrow Purging and Processing (having been held in the same years) which is another "young" research branch that has a substantial intersection zone with the one under study (MF based techniques are used for bone marrow purging): 32 vs. 24 cited disciplines, i.e., an obvious decrease. Other indirect evidences of the recent progress of the research problem are featured in Chapter 7; the structure of cited disciplines is to be compared with applicability of some selected research works to various medical and biological objectives in the following chapters.

7. BIOMEDICAL APPLICATIONS OF MAGNETIC FLUIDS A PROGRESSING AREA OF RESEARCH? (FURTHER SCIENTOMETRIC DATA)

The title hypothesis is also supported by the productivity data of the abstracts from ICMF-5 and ICMF-6 Conferences: the abstracts compendium of the ICMF-5 contains 11 works on MF biomedical applications (7.98% of the total number of abstracts), in the ICMF-6 compendium there are 32 abstracts (11.43%). The absolute increase is 190.-91%, the relative increase is 43.23%. Numbers of full papers published in the Proceedings are correspondingly 5 for the ICMF-5 (7.35% of the total amount of publications) and 13 (12.87%) for the ICMF-6, the absolute increase is 160.00%, relative increase being 75.10%; i.e., more than the relative increase of the number of all the papers published in the Proceedings of the ICMF-6 (48.53%). The portions of the biomedical papers from the biomedical abstracts are correspondingly 45.45% for the ICMF-5 and 40.62% for the ICMF-6, while the full papers/abstract part for the whole Proceedings are 49.27 and 36.07%. It means that MF biomedical applications papers' authors succeeded more in terms of publication productivity in the ICMF-6 Proceedings than the domain in general. Also, there is a substantial increase in the numbers of institutions and countries whose representatives happily published their abstracts and full papers: thus, if the representatives of only 5 countries and

13 institutions published their abstracts in the ICMF-5 compendium, in the compendium of the ICMF-6 the representatives from 11 countries and 34 institutions published their works; the corresponding data for the Proceedings being 3 countries / 7 institutions for the ICMF-5 and 8 countries / 20 institutions for the ICMF-6. The above data seems to support our hypothesis as reflecting the increase of productivity of the subdomain in all the possible terms and the appearance of newly involved institutions (or at least of institutions whose researchers become interested in participating in the top MF international forum).

8. SUBJECT STRUCTURE AND DISCIPLINARY STRUCTURE OF THE RESEARCH OF BIOMEDICAL APPLICATIONS

The obtained data on the *disciplinary* structure of *references* in the papers devoted to MF biomedical applications support the opinion that the research problem is both a highly interdisciplinary and progressive one (the latter being supported also by the data of the previous Chapter). It is also of interest to obtain a formalized notion of the thematic structure of the research themselves as reflected in the content of the ICMF-5 and ICMF-6 abstracts (to support or disprove our opinion). So as not to miss any possible trend, we read thoroughly all the corresponding abstracts, trying to classify first the *subjects* of their research.

The results of this attempt are presented in Table 4, the latter demonstrating that *three main* subjects still exist, viz. *cell separation* and *drug transportation* systems, and MF-based *imaging techniques*. As for two of them, viz. cell separation and imaging techniques, there is an apparent tendency to an increase, whereas for the use of magnetic fluids as drug carriers the increase is a minor one. Little attention seems to be paid to the studies of the interactions of MF with biological structures in general. A *visible expansion of the subject structure of the studies is obvious.* This also looks to be a sign of a research progress.

Another way of presenting the thematic structure of the research is to determine disciplines under which framework research may be classified (as it was done with the cited references). For the content of the abstracts such an attempt was also made (Table 5) since it is of an interest to compare the disciplinary structure of published and cited works. The most prominent finding plotted in Table 5 is the increase of research in such vital areas as oncology and immunology.

9. RETURNING TO SPECULATIONS: POPULAR REVIEW OF SOME RECENT WORKS ON MAGNETIC FLUIDS BASED DRUGS TRANSPORTATION SYSTEMS

Drugs transportation is being undertaken by means of an applied magnetic field to a MF drug carrier. Though the subdivision of the research is both important and promising, there is not such a great absolute increase in the number of abstracts (+40.00%), while in relative terms the *decrease* is -58.25%.

The mentioned decrease does not seem to be occasional since "such drug transporting system must have definite, very often controversial (...) characteristics:

- Particles in magnetic fluid compositions stabilized by biocompatible substances must have appropriate shape and size (...) in order to pass through capillary systems of organs and tissues without posing the threat of vessel embolisation.

- Compositions containing both [magnetic] fluid and a chemotherapeutic agent must have sufficiently high magnetization [to be captured in a target site at the physiological velocities of blood flow].

- Magnetically guided carrier systems must be able to transport the necessary amount of pharmacologically active compounds, and there must be an effective mechanism for the release of drug from the carrier at the target site.

- All components of the drug carrier complex must be non-toxic, finally biodegradable and removable from the reticuloendothelial system" [10, p. 335].

Besides these problems, it seems that just not very much attention is paid to the problem of the studies of interactions of MF with "biological structures" (i.e., "blood components, membranes of cells and subcellular structures" [11, p. 266]). However, "investigations in this field are being done in oncology (...), in the treatment of diseases of heart and blood vessels (...) and hollow organs" [10, p. 335]. There are reports of successful experimental treatment of some malignancies with the aid of water-based MF drug carriers [12] and of a number of malignancies with the aid of ferromagnetic microspheres that immobilize antitumor drugs and consist of microcrystalline ferric oxide and a polymeric matrix [13],

TABLE IV

The subject structure of the abstracts on biomedical applications published in the ICMF-5 and ICMF-6 Proceedings

Subject (purpose or sphere of application or an objective)	Number of the abstracts in the abstract compendium of the ICMF-5			of the ICMF-6		
	original	reviews	total	original	reviews	total
cell separation[3]	2	0	2	7	0	7
drug carriers	5	0	5	6	1	7
image techniques	1	0	1	6	1	7
biomedical research in general				1	0	1
alignment of biomedical assemblies	0	1	1			
experimental medicine and oncology in general				0	1	1
development of immunological compositions				1	0	1
fabrication of carbon				1	0	1
hyperthermia of cancer				1	0	1
immobilization of cytochrome-c-oxidase				1	0	1
obturation of digestive tracts external fistulas	1	0	1			
obturation of hollow organ fistulas				1	0	1
smear examination				1	0	1
studies of biotransformation of magnetic powders				1	0	1
studies of MF interactions with biological structures	1	0	1			
antiflammatory effects	1	0	1			
treatment of plants	1	0	1	1	0	1

[3] Italicized are the titles of the *main* general subjects

TABLE V

The disciplinary structure of the abstracts on biomedical applications published in the ICMF-5 and ICMF-6 Proceedings

Scientific discipline	Number of the abstracts in the abstract compendium			
	of the ICMF-5		of the ICMF-6	
	a	%	*a*	%
Biophysics	2	15.38		
Hematology	2	15.38	3	8.57
Medicine, General and Internal	2	15.38	3	8.57
Biology	1	7.69		
Oncology	1	7.69	4	11.34
Cardiovascular System	1	7.69	1	2.86
Cytology	1	7.69		
Genetics	1	7.69	1	2.86
Immunology	1	7.69	8	22.86
Surgery	1	7.69	2	5.71

on the development of a ferromagnetic antitumor dextran-ferrite [13] and on the MF obturation of hollow organ fistulas [14], on the technical possibility to use MF as the carrier for drug transportation into an occluded vessel [15]. Hence, such scientometrically defined disciplines such as oncology, surgery and cardiovascular systems are again included in the list—but this time by means of the analysis of the context of the relevant publications.

10. AGAIN REVISITING SPECULATIONS: POPULAR REVIEW OF SOME RECENT WORKS ON MAGNETIC FLUIDS BASED CELL SEPARATION SYSTEMS

MF-based and related techniques are good for cell separation systems used, e.g., for human lymphocyte subset removal, tumor cell removal, selection of self-replicating bone marrow cells, hybridoma selection, separation of endothelial cells [16].

The most acute challenge in the context of the listed applications is bone marrow transplantation which is an aid in the management of leukemia, cancer, and lethal radiation exposure. Human lymphocyte subset removal and the selection of self-replicating bone marrow cells are among the possible problems to be resolved during the procedure of bone marrow transplantation:

Removal of human lymphocyte subsets using a suitable magnetic bead labelled with an antibody to the targeted lymphocyte and being performed by methods of magnetic filtration, is still a good biological com-

promise in *allogenic* bone marrow transplantation (BMT) where graft versus host disease is to be controlled in this way and yet the graft versus leukemia effect to be retained. As for *autologous* BMT, where there may be a residuum of, e.g., leukemic cells or neuroblastoma, or, e.g., breast tumor, in the sample collected, purging of marrow samples is accepted as part of the current approach to tumor treatment. For many tumors there are specific antibodies and, using similar techniques to those for removing lymphocytes subsets, these unwanted and presumably life threatening residual malignant cells can be removed, e.g., by ferromagnetic beads or simple filtration systems although refinement of this technology is still awaited.

Separation technology using several magnetic based approaches in this field is directed towards the purification of stem cells from blood or bone marrow. Currently it is possible to regenerate human bone marrow using stem cells only, when they are obtained in this way. Techniques include the use of monosized composite polymer particles (magnetic beads) and ferrocolloids [16].

The promising feature of the mentioned and unmentioned applications is the existence of some commercial systems developed for cell separation. E.g., in [17] experiments are described on "selective removal of breast cancer cells from artificial mixtures containing fresh, healthy bone marrow cells and breast cancer cell line-derived cells" [17, p. 488] with the help of binding the lectin soybean agglutinin, mixed with polystyrene magnetic beads "Dynabeads".

The authors of [18] produced colloidal magnetite-binding erythrocytes considered for a cell processing scheme as being selective in the process of binding. Also, a technique is being developed for immobilization of polysaccharide-mediated colloidal particles onto human platelets enabling the potential use of the latter as a blood-component-based magnetic label for different cell fractionation schemes [19].

The brief outlook to the recent conference papers gives an impression that the publication increase in this area (250.00% absolute and 20.35% relative increase) is not just occasional and reflects the real state of affairs regarding the reviewed direction of the research. An enthusiasm of researchers, which is a good prerequisite for a success, is also obvious. It should be emphasized that such disciplines as immunology, surgery and radiation and nuclear medicine are again in the list of related disciplines as the result of the above analysis.

11. FURTHER SPECULATIONS: POPULAR REVIEW OF SOME MAGNETIC FLUIDS BASED IMAGE TECHNIQUES

As one of us reported, "an area where magnetic and paramagnetic fluids have been developed and established is that of the enhancement of magnetic resonance imaging. Briefly, both signal enhancement and improved tissue contrast can be achieved by using paramagnetic, superparamagnetic or ferro magnetic particles. Clearly, the needs for such a system include:

1. non-toxic particles,
2. particles giving maximum enhancement,
3. delivery of the particles to the appropriate site.

Specific receptors and linkages of the enhancing particles to those receptors by, e.g., antibodies or naturally targeting entities need more development. However, imaging of experimental myocardial infarction (...) and the gastrointestinal tract (...) have shown that the contrast manipulation may be highly effective" [16, p. 530]. Imaging for experimental inflammation should be mentioned in the same way [20].

Second, Roentgen contrast diagnostics should be mentioned. A recent example is an antitumor roentgenocontrast magnetically controlled ferromagnetic fluids described by Brusentsov et al [21] that contain 20-60 weight percent of dextran-ferrite, Dactomycin, and 40-80 weight percent of verografin or conrey.

The increase of the number of abstracts devoted to image techniques (+600.00% absolute and +140.70% relative) could hardly, however, be taken into account *seriously*, because only one paper was presented at the ICMF-5. A number of biological and medical disciplines where MF-based image techniques are applicable, is, in any case, very impressive (cardiovascular systems, internal medicine, oncology and a lot of others that are not exemplified here). The research seems to be progressing, too.

12. STILL MORE SPECULATIONS: SOME OTHER APPLICATIONS

The description of the studies of the rest—mostly specific than general—of the applications is contained in some 1/3 of the ICMF- 5 and some 36% of the ICMF-6 abstracts. There are no small groups as we see, but the distribution of the subjects—one abstract per two conferences except the "treatment of plants" (one abstract per one conference)—does not allow us to make any distinctly generalized grouping. Neither does it inspire us to produce a review of the rest of the applications.

At the same time, a new *leading* sphere of MF biological applications, viz. agriculture, demonstrated itself at the ICMF-7 in January, 1995. However: the Seventh Conference on scientometric analysis is beyond the objectives of the present study.

13. CONCLUSIONS

Magnetic fluids is a relatively "young" research branch that is termed in the same manner as its subject. It has no specialized journal totally devoted to the subject, neither an officially registered scientific society to unite the domain. In spite of these signs of an "insufficient maturity" this research branch looks very much *mature* in terms of interdisciplinarity —both as consuming the information from other disciplines and as *providing various fields of science and technology with the products of its own R&D.*

Biomedical applications of MF is a highly interdisciplinary problem. The most prominent features are: the growths of the number of disciplines being linked with it; a great number of the medical and biological disciplines, where the future practical applications of the R&D results are very promising; a sufficient increase of the links with non-medical disciplines; a stable character of the main spheres of applications (founded on the extension of the particular applications); practical applicability of MF-based techniques in cell separation procedures; growth of the number of researchers being inspired by the targets of this research problem.

The present work is based on the combination of the two approaches: *"within object"* (i.e., the analysis of the content of the problem by analytically reviewing the relevant literature) and *"beyond object"* (a scientometric—i.e., formal and quantitative—evaluation of science indicators). The study was fulfilled by the team of two scientometricians and two experts in magnetic fluids (a physician researcher and a chemist). Such an approach seems to be promising for bridging the gaps between the formal way of assessment of a scientific discipline development (that may be superficial and biased, but never prejudiced) and the assessment of the latter by the representatives of the same discipline (peer evaluation that is never superficial, seldom biased, but often prejudiced).

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