ENI AWARD 2009

CANDIDATURE PROPOSAL

1. TITLE OF THE RESEARCH:

Control of Indigenous Crude Oil Nanocolloids as the Basis of "Clean" Petroleum Nanotechnologies.

2. PRIZE SECTION

Hydrocarbon Section

3. PRINCIPAL REPRESENTATIVE OF THE RESEARCH RESULTS:

SURNAME: Evdokimov

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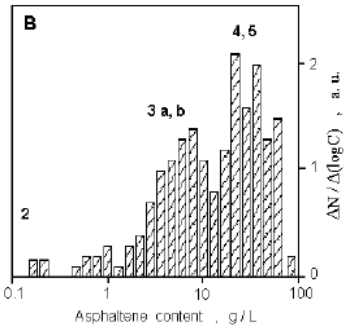
4. EVENTUAL OTHER AUTHORS OF THE RESEARCH RESULT:

Eventual co-authors of relevant publications (cf. List of Publications Form) are not proposed as other authors of the research results. For their contribution to research – cf. p.12, below.

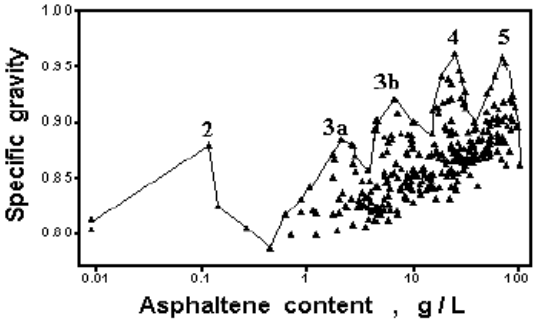
5. ABSTRACT GIVING A BRIEF DESCRIPTION OF THE RESEARCH RESULTS:

At the moment, the developed and emerging nanotechnologies in petroleum industry imply introduction into natural petroleum media of "foreign" nano-species (e.g., micellar surfactants for wetting control, fine solids for flow improvement, etc.). Most often these foreign additives by themselves cause ecological environmental problems in course of further processing of petroleum. Moreover, they spoil "the ecology of petroleum proper" in a sense that they ruin a delicate molecular and supramolecular organization of hydrocarbon media which evolved over long times in natural reservoirs. Hence, petroleum quality (e.g. with respect to extraction of light fractions), may notably diminish. On the other hand, "the ecology of petroleum proper", may be spoiled merely by improper choice of technological parameters in course of recovery, transportation, processing.

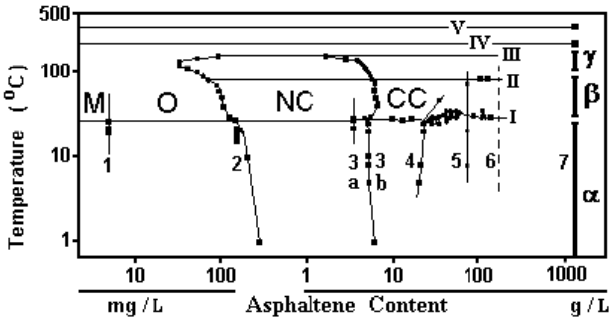
In brief, our research results revealed the existence in all petroleum media of indigenous nanoobjects, whose properties (and, hence, the properties of bulk petroleum) evolve according to universal phase diagrams, common to world's crude oils of diverse geographical/geological origin. As an illustration, consider some figures from the attached Publication 1 (cf. p.14 below).



The figure at the left shows previously non-recognized multi-peak frequency distribution of the occurrence of world's crude oils with respect to their content of nanocolloid - forming asphaltenes.



The figure at the right shows previously non-recognized multi-peak relationship of the specific gravity to asphaltene content in world's recovered crude oils. It is clear that in course of geological evolution, indigenous nanoobjects in native petroleum tend to evolve towards structural states (denoted by numbers) at the concentration boundaries of the universal phase diagram obtained in laboratory experiments, as shown below.



On one hand, these results may make some emerging petroleum nanotechnologies "clean" by eliminating the necessity of "foreign" nanospecies and controlling indigenous nanoobjects.

On the other hand, the existing industrial operations may become "clean nanotechnologies" if they will be performed with account of nano-phase transformations, i.e. according to the principle "do not harm" with respect to delicate natural nano-organization of petroleum media.

As a result, industrial application of the research results may help to improve the quality of recovered raw petroleum, or at least to prevent deterioration of naturally-evolved quality.

6. ABSTRACT - TECHNICAL DESCRIPTION OF THE RESEARCH RESULTS

1) Relevance to the activities of exploration, production, transport, distribution and transformation – the research results reveal common nanocolloid-related mechanisms of deterioration (viscosity and density increase, etc.) in crude oils of diverse geographical/geological origin in course of all above technological operations and, hence, provide means of modification of existing technologies (or developing of new ones) to prevent undesirable loss of the quality of petroleum.
2) Achievable improvement in efficiency – improvement of efficiency may be a result of expected improvement of petroleum quality, though presently there are no methods of evaluating "efficiency gain" qualitatively.
3) Contribution to sustainability of resources – this subject is directly addressed by a proposed principle "do not harm" with respect to delicate nano-level organization in reservoir and recovered crudes. By understanding concepts of nano-level sustainability, practitioners will be able to make more informed decisions about management of petroleum resources.
4) Degree of technological feasibility – very high, as emerging "clean" petroleum nanotechnologies do not require development of any sophisticated "hardware". All existing equipment may be retained, though employed with a new understanding of possible consequences of industrial operations.
5) Where the innovation may be applied – in all technological operations with liquid petroleum-based media (crude oils, condensates, emulsions, etc.), involving changes of ambient parameters (temperature, pressure) or composition (mixing of oil streams in reservoir, in course of transportation, storage and processing).
6) Cost-benefit ratio of the technology proposed – the cost of development of "clean" petroleum nanotechnologies amounts mainly to comparatively low one-time expenses of re-educating/replacing personnel and of some additional company-oriented research. Hence, a favorable ratio is expected to any benefits of quality improvement in mass production of raw petroleum.
7) Potential impact on the energy system – decreasing production costs of raw and processed petroleum due to eliminating some possible quality losses.
8) All major results have been achieved within the five-year period 2003-2008 (cf. List of Publications Form)

7. BRIEF EXPLANATION OF THE MOTIVES OF THE RESEARCH RESULTS SUBMITTED FOR THE FIRST TIME:

One of the primary motives underlying this research initiative stems from previous scientific experience of the research supervisor in the field of thermonuclear energy, in particular in experimental studies of atomic/molecular processes at solid interfaces and in small (to use contemporary term, nano-sized) clusters. An important conviction from previous research practice was that supramolecular organisation of matter in small (nano) domains and delicate processes of re-arrangement of this nano-heterogeneous organization may, under appropriate conditions, drastically alter the "coarse", macroscopically measurable bulk properties of any studied objects. At the start of present research the state-of-art in petroleum engineering was to consider petroleum media as homogeneous in principle, its macroscopic parameters being smooth functions of contents of various constituents. However, our in-depth analysis of existing databases of world's recovered crude oils revealed non-smooth, polyextreme character of these functions which we attributed to structural phase transformations in nanocolloids of petroleum asphaltenes. To convince petroleum practitioners in the supreme importance of nano-heterogeneous nature of petroleum, a series of laboratory experiments were performed, which e.g. provided a temperature-concentration phase diagram of petroleum nanocolloids, apparently inherent to any crude oil.

8. BRIEF EXPLANATION OF THE MOTIVES OF THE RESEARCH RESULTS ALREADY PRESENTED IN PAST EDITIONS.

____The results had not been presented in past editions _____

9. DURATION OF THE RESEARCH:
From 2003 and still ongoing _____

10. DIMENSION OF THE RESEARCH:

Personnel – 1 professor; 3 docents (ass. professors); 1 senior researcher; 2 lab. Technicians; 12 B.Tech. students; 5 M.E/Tech. students; 2 Ph.D. students.
Funding – on average, ca. 100000 – 150000 roubles annually (can not be directly evaluated in EU, USA or other currencies due to crucial differences in Russia's economic system and funding policy).

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11. SOURCES OF FUNDING

Russian Academy of Science;
Russian Ministry of Education;
Government of Moscow;
GASPROM Company (Moscow);
RITEK Company (Moscow);
International Fuel & Energy Association (Moscow);
Russian Gubkin State University of Oil and Gas.

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12. ROLE OF EACH RESEARCHER THAT HAS COLLABORATED IN OBTAINING THE RESEARCH RESULTS PROPOSED TO CANDIDATURE:

I.N. Evdokimov - Research Initiator & Supervisor, Key Researcher;
N.Yu. Eliseev – Chief Administrator, Funding Supervisor;
V.A. Iktisanov – Industrial Contacts, Provision of Petroleum Samples and Databases;
A.P. Losev, B.R. Akhmetov (Ph.D. students) – Equipment Maintenance, Experimental Measurements, Data Processing and Analysis;
Y.O. Efimov, M.A Novikov, D.Yu. Eliseev (M.E/Tech. students) – Experimental Measurements, Assistance in Data Processing.

13. LIST AND TITLE(S) OF THE PATENTS RELEVANT TO THE RESEARCH RESULTS:

NO recent patents relevant to the research results

14. LIST UP TO THREE PUBLICATIONS ON SCIENTIFIC REVIEWS REGARDING THE RESEARCH RESULTS TO BE SEND ATTACHED TO THIS FORM IN ELECTRONIC COPY

1. **I.N. Evdokimov** "Fine Phase Transformations" In Petroleum - The Basis for Emerging Nanotechnologies. In: *Petroleum Science Research Progress*, Editor, K.L. Montclaire, Nova Science Publishers, Inc., New York, 2008. p.235-259.
2. **I.N. Evdokimov** T-C Phase Diagram of Asphaltenes in Solutions. *Petroleum Science and Technology*. 2007. Vol.25, No.1-2, p.5-17.
3. **I.N. Evdokimov** Bifurcated correlations of the properties of crude oils with their asphaltene content. *Fuel*. 2005. Vol.84. Iss.1. p.13-28.

DATE: 08 October 2008

SIGNATURE OF THE MAIN REPRESENTATIVE OF THE RESEARCH RESULTS:

(I. N. Evdokimov)

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Certificate and Technical Assessment

The proposed Research Results have been initiated and supervised by Professor I.N. Evdokimov (Physics Department, Faculty of Oil and Gas Field Development, Gubkin Russian State University).

In 2007, by nomination of Academic Council of the Faculty of Oil and Gas Field Development, these results have been awarded the Baybakov Gold Medal of International Fuel and Energy Association – a non-government organisation of leading and experienced managers, specialists and scientists in petroleum industry.

One of the reasons for high assessment by petroleum practitioners of research results in fundamental science was a suggested introduction of "nano-ideology" into planning and application of industrial oil and gas technologies. The authors of these results persuasively demonstrated that the lack of effectiveness of a number of oil and gas production technologies often resulted from the presence of persistent stereotypes of thinking. The formulation and implementation of these technologies was based on information about the features of physical-chemical properties of crude oils, often derived from textbooks written by our fathers and even grandfathers. For many professionals in the field of oil production, these data seem to be inviolable, axiomatic. But time passes and it turns out that the "sanctity" of this knowledge is only apparent, and many of «axioms» must be revised, and some - changed to the opposite.

The discussed research results demonstrated that time has come to change old views on the mechanisms underlying some of the observed variations of oil properties in the development field, in primary production and transportation of products. This complex research revealed new information about drastic changes in the macroscopic operationally-significant properties of produced crude oils, induced by changes in its microscopic (nanoscale) phases formed, mainly by petroleum asphaltenes.

The obtained data provided a scientific basis for reviewing many of well-known «axioms» oil and gas production, for example, allegations that:

- Increase in the content of high-molecular-weight components (especially of asphaltenes) invariably leads to a monotonically increasing density and viscosity of oil;
- The quality of heavy oil always improves after mixing (commingling) with light oil;
- Thermal treatment of crude oils always improves their rheological properties;

In fact, an analysis of these processes with an account of newly obtained information on petroleum nano-phases, shows that:

- Dependencies of the density and viscosity of crude oils on their asphaltene content have a pronounced multi-peak character. These parameters increase sharply in oils, with asphaltene contents corresponding to concentration-defined nano-phase boundaries (e.g. at asphaltene concentrations close to 5-7 mg/l; 100-150 mg/l; 1-3 g/l; 7-10 g/l; 20-35 g/l and 70-90 g/l).
- The quality of crude oil mixture may be below the quality of both parent oils, if after commingling, the composition of the mixture becomes closer to the above nano-phase boundaries.
- Thermal treatment becomes less effective (and even leads to the deterioration of rheological properties of oil) if it is carried out in conditions, close to temperature-defined nano-phase boundaries (around 25-30 ^{o}C; 90-100 ^{o}C and 170-180 ^{o}C).

In general terms, the assessed research results have shown that now there is enough evidence to consider native crude oils themselves as «association nano-fluids», natural objects of emerging petroleum nanotechnologies.

Scientific credibility and practical value of the assessed research results have been verified by multiple publications in peer-reviewed scientific and technical journals, and by reports at 10 international and 7 national conferences. The results became a basis for published monograph and 3 University teaching manuals. On the basis of these results, in 2007, the Faculty of Oil and Gas Field Development have introduced a new program for education of "Masters in Engineering and Technology", namely that of "Oil & Gas Nanotechnologies for Reservoir Development" (academic and scientific supervisor – professor I.N. Evdokimov).

Dean of Faculty of Oil and Gas Field Development,
Gubkin Russian State University of Oil and Gas
Professor I. T. Mischenko (Signature)

Date: "13" October 2008

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List of Publications Form

*(Some English-Language Publications of **I.N. Evdokimov**, Relevant to the Subject of Application, Listed in Reverse Chronological Order):*

1) **Evdokimov I.N.** "Fine Phase Transformations" In Petroleum - The Basis for Emerging Nanotechnologies. In: *Petroleum Science Research Progress*, Editor, K. L. Montclaire, Nova Science Publishers, Inc., New York, 2008. p.235-259.

2) **Evdokimov I.N., Efimov Y.O., Losev A.P., Novikov M.A.** Morphological Transformations of Native Petroleum Emulsions. I. Viscosity Studies. *Langmuir*, 2008, Vol.24, No.14, p.7124-7131.

3) **Evdokimov I.N., Losev A.P.** Features of analysis of associative hydrocarbon media. Applicability of refractometric methods. *Chemistry and Technology of Fuels and Oils*. 2007. Vol.43, No.2, p.140-146.

4) **Evdokimov I.N., Losev A.P.** Potential of UV-Visible Absorption Spectroscopy for Characterizing Crude Petroleum Oils. *Electronic scientific journal "Oil and Gas Business"*, Ufa, 2007, 21 pp.

5) **Evdokimov I.N., Losev A.P.** Effects of molecular de-aggregation on refractive indices of petroleum-based fluids. *Fuel*. 2007. Vol.86, No.15, p.2439-2445.

6) **Evdokimov I.N.** T-C Phase Diagram of Asphaltenes in Solutions. *Petroleum Science and Technology*. 2007. Vol.25, No.1-2, p.5-17.

7) **Evdokimov I.N., Losev A.P.** On the Nature of UV/Vis Absorption Spectra of Asphaltenes. *Petroleum Science and Technology*. 2007. Vol.25, No.1-2, p.55-66.

8) **Evdokimov I.N., Eliseev N.Yu., Losev A.P., Novikov M.A.** Emerging Petroleum-Oriented Nanotechnologies for Reservoir Engineering. *Proceedings of the 2006 SPE Russian Oil and Gas Technical Conference "Technology for world class resources"*, 3-6 October 2006, Crocus Expo, Moscow, Russia. CD-Rom Edition. 24 pp.

9) **Evdokimov I.N., Eliseev N.Yu.** Thermally Responsive Properties of Asphaltene Dispersions. *Energy & Fuels*. 2006. Vol.20. No.2, p.682-687.

10) **Evdokimov I.N., Eliseev N.Yu., Akhmetov B.R.** Asphaltene Dispersions in Dilute Oil Solutions. *Fuel*. 2006. Vol.85, No.10-11, p.1465-1472.

11) **Evdokimov I.N., Eliseev N.Yu.** Colloidal Structures of Petroleum Residues Long-Lived in Metastable States. *Chemistry and Technology of Fuels and Oils*. 2005. Vol.41, No.3, p.230-235.

12) **Evdokimov I.N., Eliseev N.Yu., Iktisanov V.A.** Excess density in oilfield water - crude oil dispersions. *Journal of Colloid and Interface Science*. 2005. Vol.285. No.2. p.795-803.

13).**Evdokimov I.N**. A Transition From Monomeric To Associated Asphaltenes in Crude Oil Solutions. *Proceedings of the 2nd Mercosur Congress on Chemical Engineering (ENPROMER 2005)*. Village Rio das Pedras, Rio de Janeiro, Brazil, 2005. CD-ROM Edition. 10 pp.

14) **Evdokimov I.N.** Bifurcated correlations of the properties of crude oils with their asphaltene content. *Fuel*. 2005. Vol.84. No.1. p.13-28.

15).**Evdokimov I.N., Eliseev N.Yu., Eliseev D.Yu.** Effect of asphaltenes on the thermal properties of emulsions encountered in oil recovery operations. *Fuel*. 2004. Vol.83. No.7-8. p.897-903.

16) **Evdokimov I.N.** Well-defined metastable (transient) states of asphaltene colloids. *Proceedings of The 2004 International Conference on Heavy Organic Depositions (HOD 2004)*, Los Cabos, Baja, Mexico, November 2004. CD-Rom Edition. 8 pp.

17) **Evdokimov I.N., Eliseev N.Yu., Akhmetov B.R.** Initial stages of asphaltene aggregation in dilute crude oil solutions: studies of viscosity and NMR relaxation. *Fuel*. 2003. Vol.82. No.7, p.817-823.

18) **Evdokimov I.N., Eliseev N.Yu., Eliseev D.Yu.** Thermophysical properties and phase-behaviour of asphaltene-containing petroleum fluids. *Fluid Phase Eqilibria.* 2003. Vol. 212, No.1-2. p.269-278.

19) **Evdokimov I.N., Eliseev N.Yu., Akhmetov B.R.** Assembly of asphaltene molecular aggregates as studied by near-UV/visible spectroscopy. II. Concentration dependencies of absorptivities. *Journal of Petroleum Science and Engineering.* 2003. Vol.37. No.3-4. p.145-152.

20) **Evdokimov I.N., Eliseev N.Yu., Akhmetov B.R.** Assembly of asphaltene molecular aggregates as studied by near-UV/visible spectroscopy. I. Structure of the absorbance spectrum. *Journal of Petroleum Science and Engineering*. 2003. Vol.37. No.3-4. p.135-143.

21) **Evdokimov I.N., Eliseev D.Yu., Eliseev N.Yu**. Negative Viscosity Anomaly of Liquid Petroleum Products after Heat Treatment. *Chemistry and Technology of Fuels and Oils*. 2002. Vol.38, No.3, p.171-177.

22) **Akhmetov B.R., Evdokimov I.N., Eliseev N.Yu.** Some Features of the Supramolecular Structures in Petroleum Media. *Chemistry and Technology of Fuels and Oils*. 2002. Vol.38. No.4, p.266-270.

23) **Evdokimov I.N., Eliseev N.Yu.** Effect of Asphaltenes on the Thermal Properties of Petroleum and Bitumen Emulsions. *Chemistry and Technology of Fuels and Oils*. 2002, Vol.38, No.6, p.374-380.

24) **Evdokimov I.N., Eliseev N.Yu., Eliseev D.Yu.** Rheological evidence of structural phase transitions in asphaltene-containing petroleum fluids. *Journal of Petroleum Science and Engineering*. 2001. Vol.30. No.3-4. p.199-211.

(Russian-Language Monograph and University Textbooks, Relevant to the Subject of Application, Published in 2007-2008):

Evdokimov I.N. *Incompatibility Problems in Commingling Crude Oil Streams.* Published by Gubkin Oil&Gas University, Moscow, 2008. – 93 pp.

Evdokimov I.N., Losev A.P. *Indigenous Nanoobjects in Petroleum Media*. Published by Gubkin Oil&Gas University, Moscow, 2008. – 104 pp.

Evdokimov I.N., Losev A.P. *Different Types of Nanotechnologies – Forced Assembly of Atomic/Molecular Structures and Self-Assembly of Nanoobjects*. Published by Gubkin Oil&Gas University, Moscow, 2008. – 80 pp.

Evdokimov I.N., Losev A.P. *Potential of Optical Research Methods for Monitoring Oil Field Development*. “Neft I Gas” Publishers, Moscow, 2007. – 228 pp.