Devoted to 100 Anniversary of Professor Mikhail Slinko

15.09.1914 – 18.07.2008

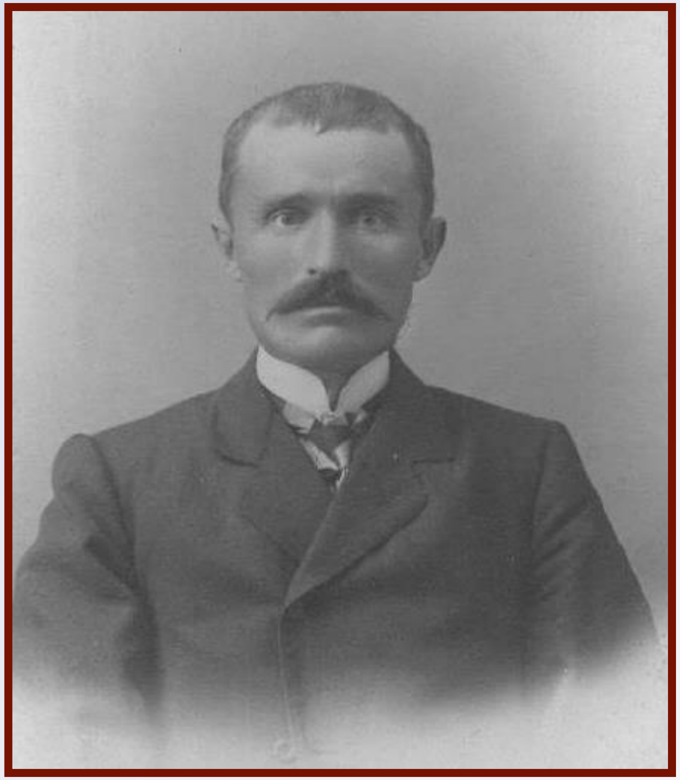
MIKHAIL GAVRILOVICH SLINKO - as a PERSON, a SOLDIER and a SCIENTIST («M.G.»)

Prof. Marina SLINKO

FAMILY

Father

Gavrila Artem'evich SLINKO



(1874 – 1949)

Mother

Vassa Gur’janovna SLINKO

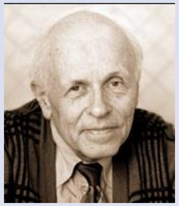
(1884-1974)

FATHER 1914

G.A. SLINKO was a driver and mechanical engineer.
During the First World War was a driver of a field ambulance and saved many poisoned men during the gas attack of German troops.
He was awarded by one of the highest decoration- St.George cross.

SCHOOL 1922 - 1932

- **Physicists**
  Andrei Saharov



  B.P. Gukov
  M.V.Volkenstein
  S.M.Rutov
  G. Zatsepin
- **Engineers**
  S.N.Chrushev
- **Artists**
  Vera Holodnaja
  Alexei Batalov
  Marija Mironova
  Igor Il'inskii
  Alexander Shirvindt

- **Poets**
  Marina Tsvetaeva

- **Mathematicians**
  V.J.Kozlov
- **Chemists**
  Nikolai Plate
- **Historians**
  S.S.Shmidt
  N.Edelman
- **Lawyers**
  G.P.Padva

Many outstanding Russian scientists, architectures, poets, musicians and artist were graduated from the school N10.

SCHOOL graduated in 1932

Director Ivan Kuzmich Novikov-the talent teacher, created the new theory of secondary school education. His book «The planning of the work in school» published in 1947 was translated into 9 languages.

Work and Study 1932-1941

<table>
<tr><th>Years</th><th colspan="4">Places of work and study</th></tr>
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<tr><td>1941</td></tr>
</table>

Teachers 1932-1937

GIPROCHIM and Mendeleev Institute

Prof. Nokolai YUSHKEVICH

1885-1937

- **From 1933 to 1937 simultaneously he was a professor of the Mendeleev University of Chemical Technology, Leading engineer of ministry of Chemical Industry and the ministry of the heavy Industry of the USSR .**
- **The main scientific results of prof. N.F. Yushkevich:**
  - Yushkevich method of sulfur production from pyrites;
  - The development of active vanadium catalysts for sulfuric acid production
  - (Yushkevich N.F., Shochin I.N. “Active vanadium catalyst for sulfuric acid production and the change of Pt catalyst for the new vanadium catalyst” The Journal of Russian Chemical Industry, 1929).

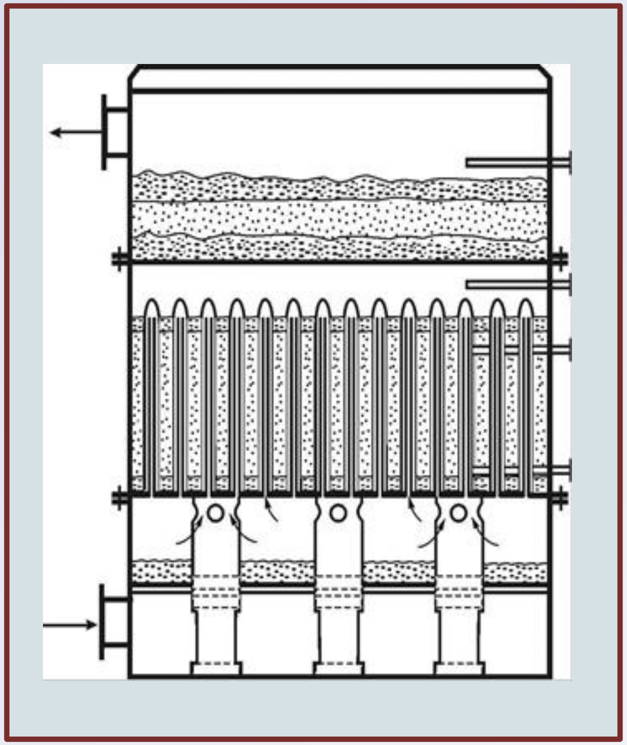
The unity of theory, practice and education

From 1933- on the position of Chemical Engineer in Giprochim and Mendeleev Institute

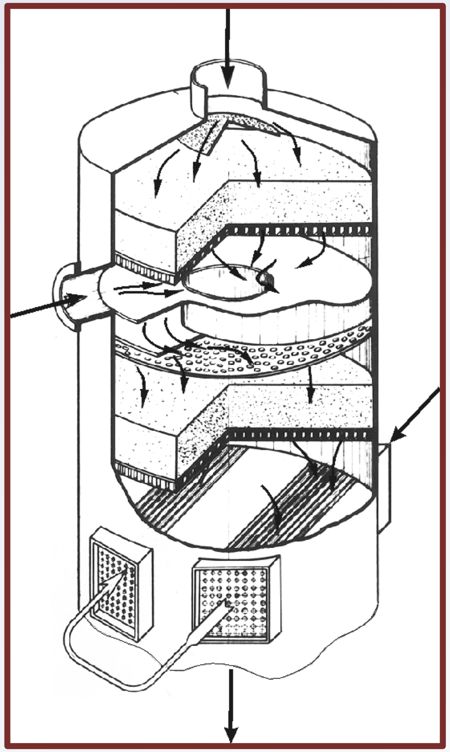
- Under the supervision of Nicholai Yushkevich the following work has been done:
- 1932 - participated in design and startup of the plant sulfur production from pyrites in Kalat (Ural in Russia)
- 1932 - Setting in and mathematical analysis of a lead tower chamber process of sulfuric acid production in Voskresensk (Moscow region)
- 1933-1935 - Mathematical modeling of the replacement of platinum catalysts to vanadium catalysts for the use of the catalytic contact process of sulfuric acid production

Reactor K-39 1937-1939

Reactor K-39, the main reactor of sulfuric acid production was designed



Reactor from USA of Selden firm

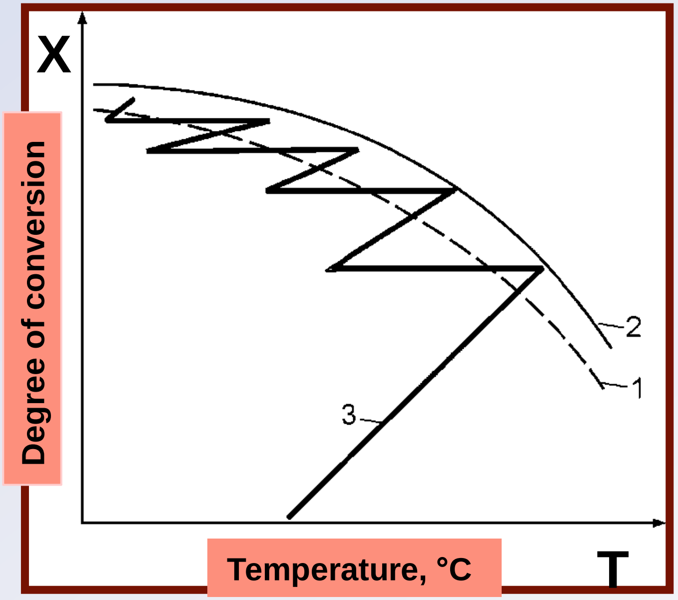


M. G. SLINKO designed a reactor for the oxidation of SO_2 into SO_3 in the production of sulfuric acid by the contact process with adiabatic catalyst layers and intermediate cooling between the layers.

Medal of the State Stalin Prize, 1943

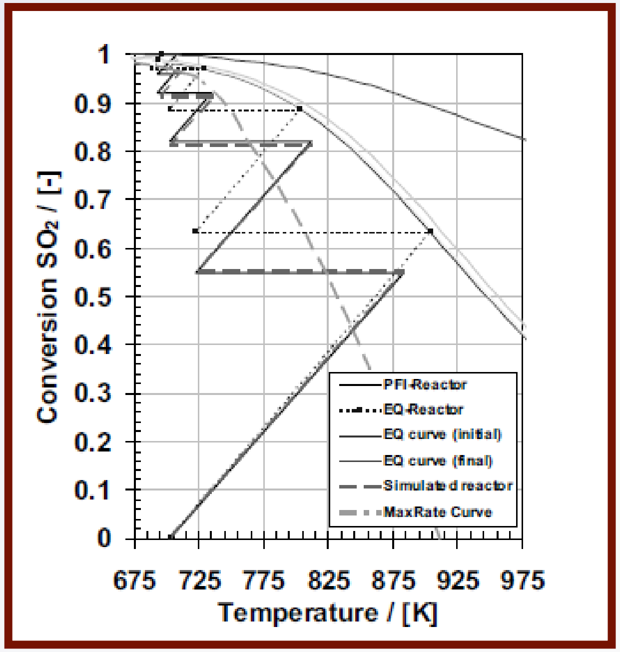
Beginning of Mathematical Modeling of Chemical Reactors 1937-1939

The apparatus was designed by solving nonlinear differential equations by graphic and other approximate methods.



G.K. Boreskov, M.G. Slinko, Zh. Prikl. Khim 16 (9-10), 377, 1943. // Principles of the design of Contact Reactors for reversible exothermic reactions

Optimization studies in sulfuric acid production by Anton A. Kiss, Costin S. Bildea, Peter J.T. Verheijen



16th European Symposium on Computer Aided Process Engineering and 9th International Symposium on Process Systems Engineering, W. Marquardt, C. Pantelides (Editors), 2006 Elsevier

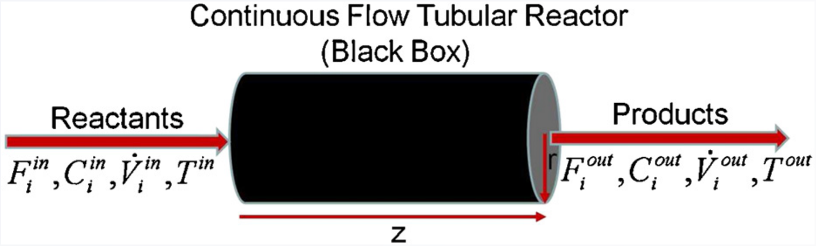
Theory of similarity and the black box methods were rejected for mathematical modeling of chemical reactors 1937-1939

«M.G.» demonstrated that similarity theory cannot be applied for the scale-up and design of chemical reactors

From one side to keep the same the reaction rate $\frac{L}{v}$ must be constant

From the other side to keep the same the influence of hydrodynamics upon the reaction rate in order to keep constant the Pe criteria $L \times v$ must be constant

L is the characteristic length, ***v*** the velocity.



Also «M.G.» denoted the treating a reactor as a black box. The method of multiple-correlations to find a functional correlations between parameters at the inlet and outlet of a reactor were rejected, because they did not reflect the peculiarities of the process and could not serve as a basis for the scaling-up.

First publications 1935-1937

Prof. Malin Konstantin Mikhajlovich – one of the leading scientists of Scientific Institute of Fertilizers and Pest Control.

Under the supervision of prof. Malin 2 textbooks were published, where some calculations of MG were included.


К. М. МАЛИН

ТЕХНОЛОГИЯ
СЕРНОЙ КИСЛОТЫ
И СЕРЫ

**K.M.Malin,
I.D.Peisachov, N.L.Arkin,
M.G.Slinko**

TECHNOLOGY OF SULFURIC ACID AND SULFUR

Part 1
Part 2

Publisher of chemical literature of USSR

1935
1937

1932-1941

Friendship with G.K.Boreskov

M.G. Slinko

G.K. Boreskov

- G.K. Boreskov, M.G. Slinko "Simulations of tubular contact reactor for SO_2 oxidation" Russian Journal of Chemical Industry, 1936, 13, N4, 221-225
- G.K. Boreskov, M.G. Slinko "Simulations of tubular contact reactor for SO_2 oxidation" Russian Journal of Chemical Industry, 1936, 13, N5, 287-294
- K.A .Malin, N.L. Arkin, G.K. Boreskov, M.G. Slinko "Technology of sulfuric acid production" Goschimisdat, Moscow, 1941
- "Principles of the design of contact apparatuses for reversible exothermic reactions" G.K. Boreskov, M.G. Slinko, Zh. Prikl. Khim, 1943 16 (9-10), 377

Work and Study 1932-1941

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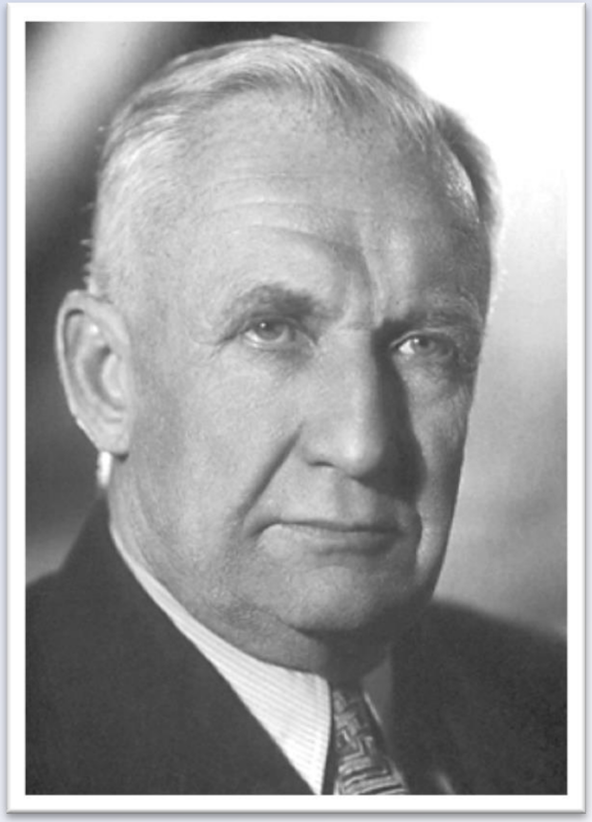
Teachers 1935-1941

MOSCOW STATE UNIVERSITY



Prof. Igor Yevgenyevich Tamm
1895 – 1971

- An outstanding theoretical physicist, the Nobel Laureate in Physics for the year 1958 together with Pavel Cherenkov and Ilya Frank for the discovery and the interpretation of the radiation of electrons moving through matter faster than the speed of light (the Cerenkov effect)
- Igor Tamm was first to demonstrate high energy electron levels in the surface caused by the difference between the binding forces at the surface and in the bulk

I. Tamm (1932). "On the possible bound states of electrons on a crystal surface". *Phys. Z. Soviet Union* 1: 733.

- **Diploma topic of M.G. Slinko: definition of interference in the electronic states associated with the statistical fluctuations due to the discrete structure of matter and the thermal motion of charge carriers**

19 of June 1941

«M.G.» Graduated from Moscow State University with Honors Diploma

ИЗВЕСТИЯ СОВЕТОВ ДЕПУТАТОВ ТРУДЯЩИХСЯ СССР

19

Students of physical department of MSU, graduated with honours diploma

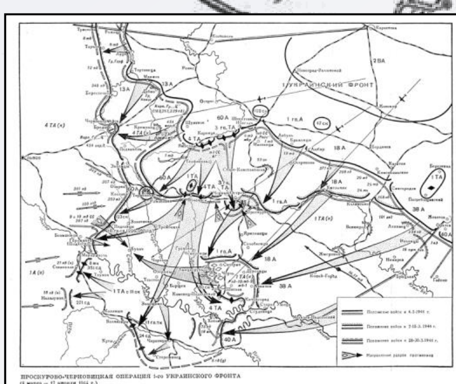
(From left to right : Zatsepin, Panchenko, Slinko, Petrov, Chentsov)

Second World War

1941-1945

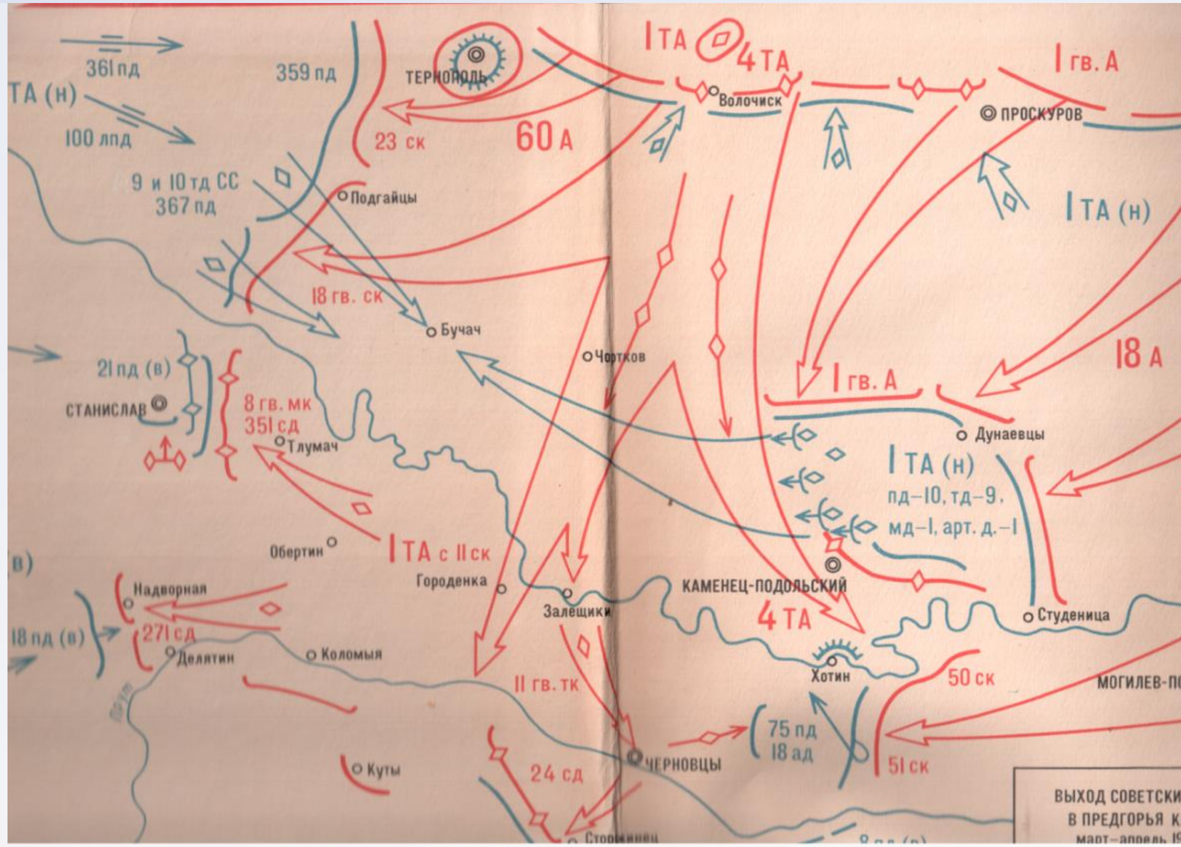
Head of the Fuel Supply Department of 1-st Tank Armi

Platoon commander



Struggle for the West Ukraine

1943



2000 tons of light oil were extracted In Karpat mountains and were distributed among 546 tanks, 3432 lorries, 585 cannons и 31 rocket launcher

V. F. Konkov, Rear services and supply of Soviet Army, (in Russian) 1982, N6, p.32

Returning to the peaceful life 1946

G.K.Boreskov, 1946, the head of the laboratory of technical catalysis In Karpov Institute

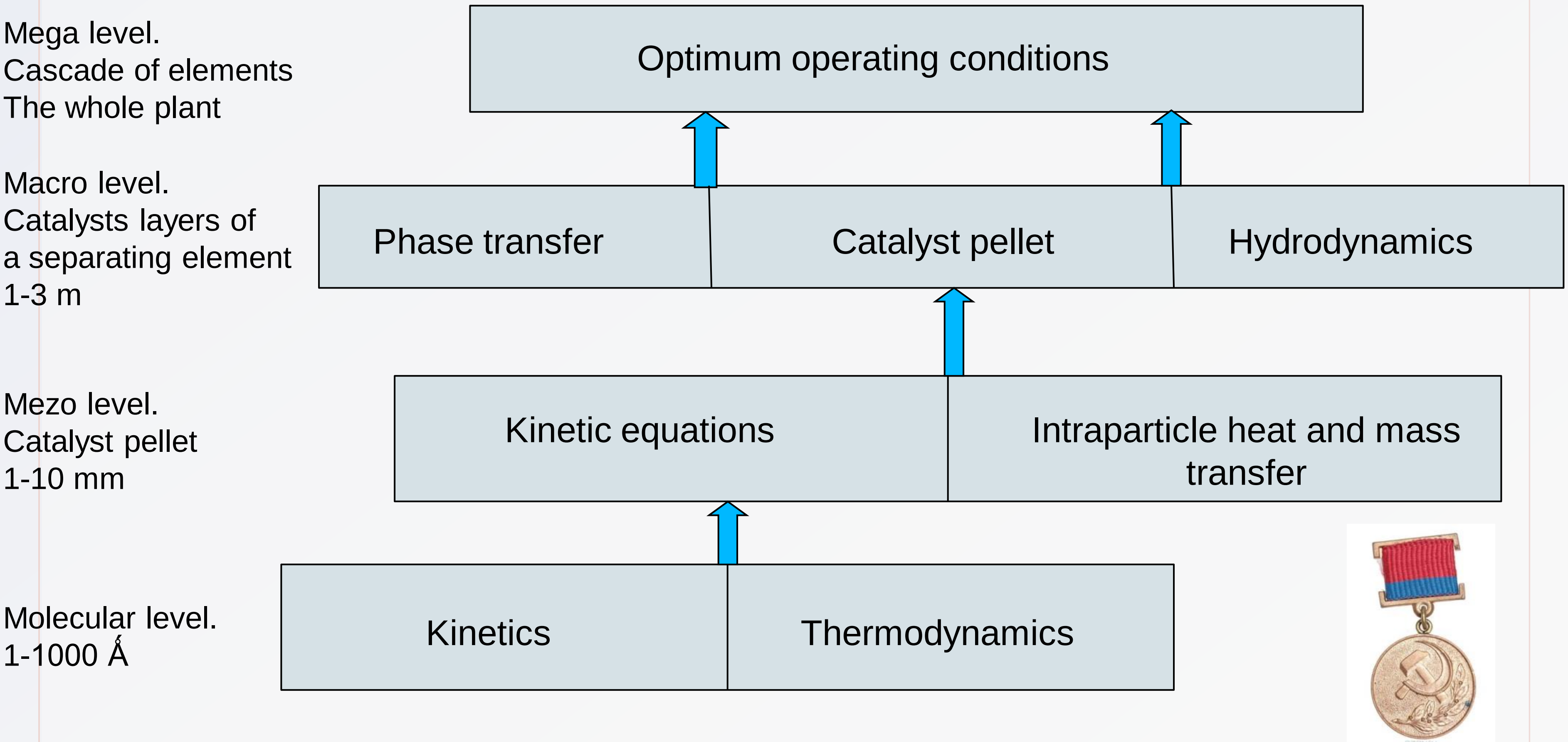
G.K. Boreskov and M.G. Slinko

Karpov institute - one of the main Institutes of Ministery of Chemical Industry

In 1946-1949 Karpov Institute was involved in atomic project

Atomic Project 1946-1948

Heavy Water Production by Catalytic Hydrogen-steam Exchange



1948-the plant for heavy water production in Chirchik city in Uzbekistan began to work.

In 1972 on the basis of the results of mathematical modelling the intensification of plant for heavy water production in Ukraine had been done and this work was awarded with the State prize of Ukraine.

Atomic Project 1946-1948

Kinetics of Catalytic Hydrogen-steam Exchange Reaction over Ni-Cr catalysts $HD + H_20 \leftrightarrow H_2 + HDO$

The first level

$$W_r = k_2(\alpha c_{HDO}\lambda^{0.5} - c_{HD}\lambda^{-0.5})$$

where W_r-real reaction rate, α-separation factor, $\lambda = \frac{P_{H_2}}{P_{H2O}}$

The second level-the catalyst pellet

$$W_{obs} = S\left[2D\int_{C_c}^{C_s} W_r(c)dc\right]^{0.5}$$

$$k_{obs} = S\left[\frac{k_2 D_1}{A\alpha + B\frac{D_1}{D_2}}\right]^{0.5}$$

A and B factors, which determine the dependence of direct and reverse reaction upon the other parameters, which were nearly constant; D_1 and D_2-diffusion coefficients of hydrogen and water vapor

1949 - PhD work on kinetics of isotope exchange between hydrogen and water

1952, M.G.Slinko, G.K.Boreskov"About kinetics of reversible reactions in the region of internal diffusion" Russian J.Phys.Chem, v.26, N2, 235

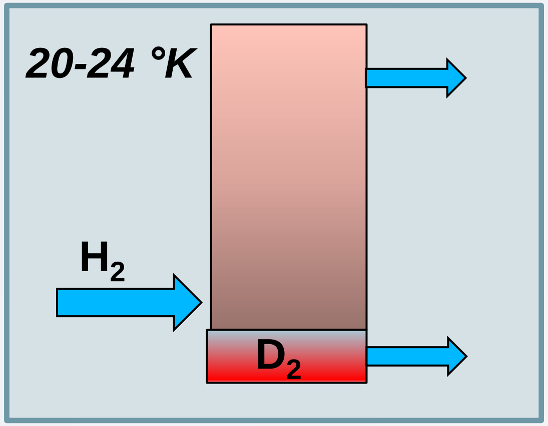
1965, E.S. Nedumova, G.K. Boreskov, M.G. Slin'ko "Kinetics of isotope exchange between hydrogen and water vapor over Ni catalysts" 1.Effect of transport processes on reaction rate. Kinetica I kataliz, 6, N1, p. 65

1965, E.S. Nedumova, G.K. Boreskov, M.G. Slin'ko "Kinetics of isotope exchange between hydrogen and water vapor over Ni catalysts" Effect of pressure in the region of the internal diffusion. . Kinetica I kataliz №2, p. 360.

Atomic Project

1952-1954

The method of heavy water production-low temperature distillation of the liquid hydrogen



To avoid an explosion the concentration of oxygen in hydrogen had to be less than 10^{-10} molar fractions, i.e. one molecule of oxygen for 10^{10} molecules of hydrogen.

J. Stalin was the leader of USSR from the mid-1920-s until his death in 1953

L.P. Beria was chief of the Soviet security and secret police apparatus

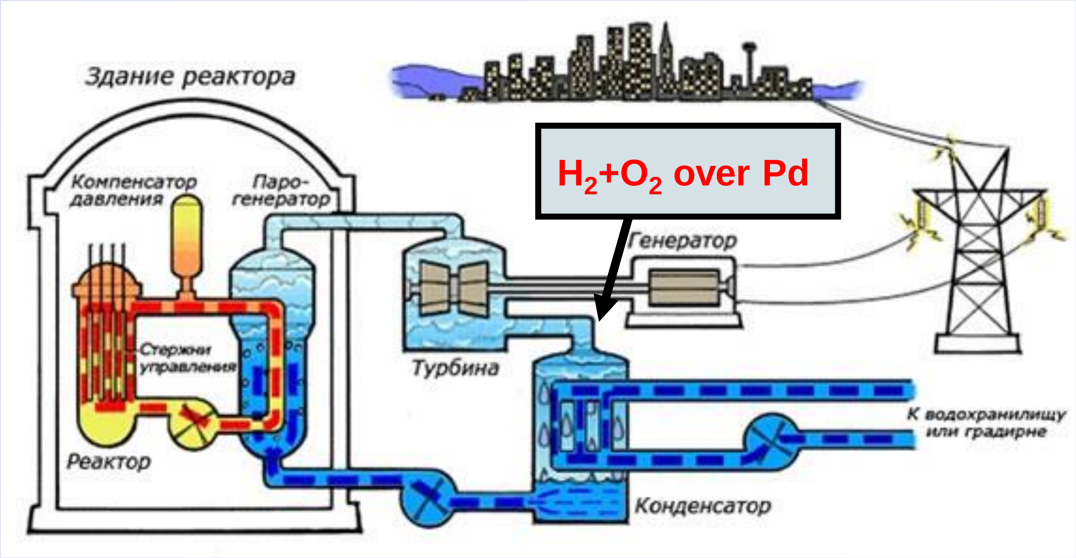
A.P. Alexandrov was a Soviet and Russian physicist, president AS USSR in future

Dr. M.G.Slinko

Atomic Project

1953-1954

The first in the world Obninsk Nuclear Power Station was designed



Pressurized Water Reactor (PWR)

Academician Kurchatov I.V.

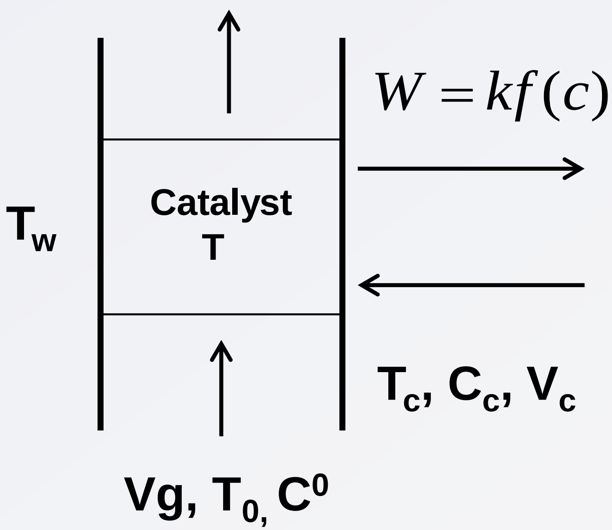
Protection of nuclear installations from a blast of the explosive air gas mixture formed as a result of water radiolysis in atomic reactors..

In its 48 years of operation there were no significant incidents resulting in radioactive release to the environment exceeding permissible limits.

The ignition of hydrogen was the main reason of a blast at a Japanese atomic power reactor in Fukushima in 2011.

Stability of a reactor with a (well mixed) bed with exothermic reaction

1953-1954



For all types of heat transfer

$$T - T_0 < \frac{E}{RT^2}(P_m - U) \quad \text{where}$$

$$U = \frac{\lambda c_v (T_w - T_0) + \mu c_c (T_w - T)_c}{(\alpha S_n + \lambda c_v + \mu c_c)\dfrac{RT^2}{E}}$$

Heat transfer only through a wall

$$\frac{T - T_w}{E/RT^2} < 1 + (c_0 - c)\frac{\partial \ln f(c)}{\partial c}$$

Heat transfer only with the circulating catalyst

$$\frac{T - T_c}{E/RT^2} < 1 + (c_0 - c)\frac{\partial \ln f(c)}{\partial c}$$

Heat transfer for autothermic processes

$$\frac{T - T_0}{E/RT^2} < 1 + (c_0 - c)\frac{\partial \ln f(c)}{\partial c}$$

$$P_m = 1 + (c_o - c)\frac{\partial \ln f(c)}{\partial c}$$

Criteria of temperature difference-determines the maximum temperature difference between catalyst temperature and temperature of initial gas or a wall

M.G.Slinko, Kinetika and Catalysis, v.1, N1, 1960, 153

Boreskov, G.K. and Slinko M.G., *Chem. Eng. Sci.*, 1961, vol. 14, p. 259.

ESCRE (1960) Netherlands

Instructor for the Novel Technology Department of the Central Committee of the USSR Communist Party

1956-1959

«M.G» was participated in the development of a 7 years plan of the development of Chemical Industry 1959-1965

«M.G» was a speech-write of N. S. Chrushev during XXI Congress of the CPSU concerning the questions of Chemical industry

The decision of the foundation of the Institute of catalysis was included into the materials of May Plenum of the USSR communist party in 1958.

The world's first case of mathematical modeling of a catalytic process on a computer 1958

MN-7, a vacuum-tube analog computer, which could solve systems of nonlinear ordinary differential equations up to the sixth order.

V.B. Scomorokhov

M.G.Slinko

Using MN-7 computer the exothermic catalytic reaction of ethylene oxidation to ethylene oxide was simulated.

Slinko M.G. "The role of mass and heat transfer processes during ethylene oxidation" Russian J.Phys.Chem.,1958, №4, v. 32. p. 943
Slinko M.G. "The influence of heat and mass transfer upon the rate of ethylene oxidation Chemical Industry, 1958, №3, p. 10

1959

Foundation of the Institute of Catalysis

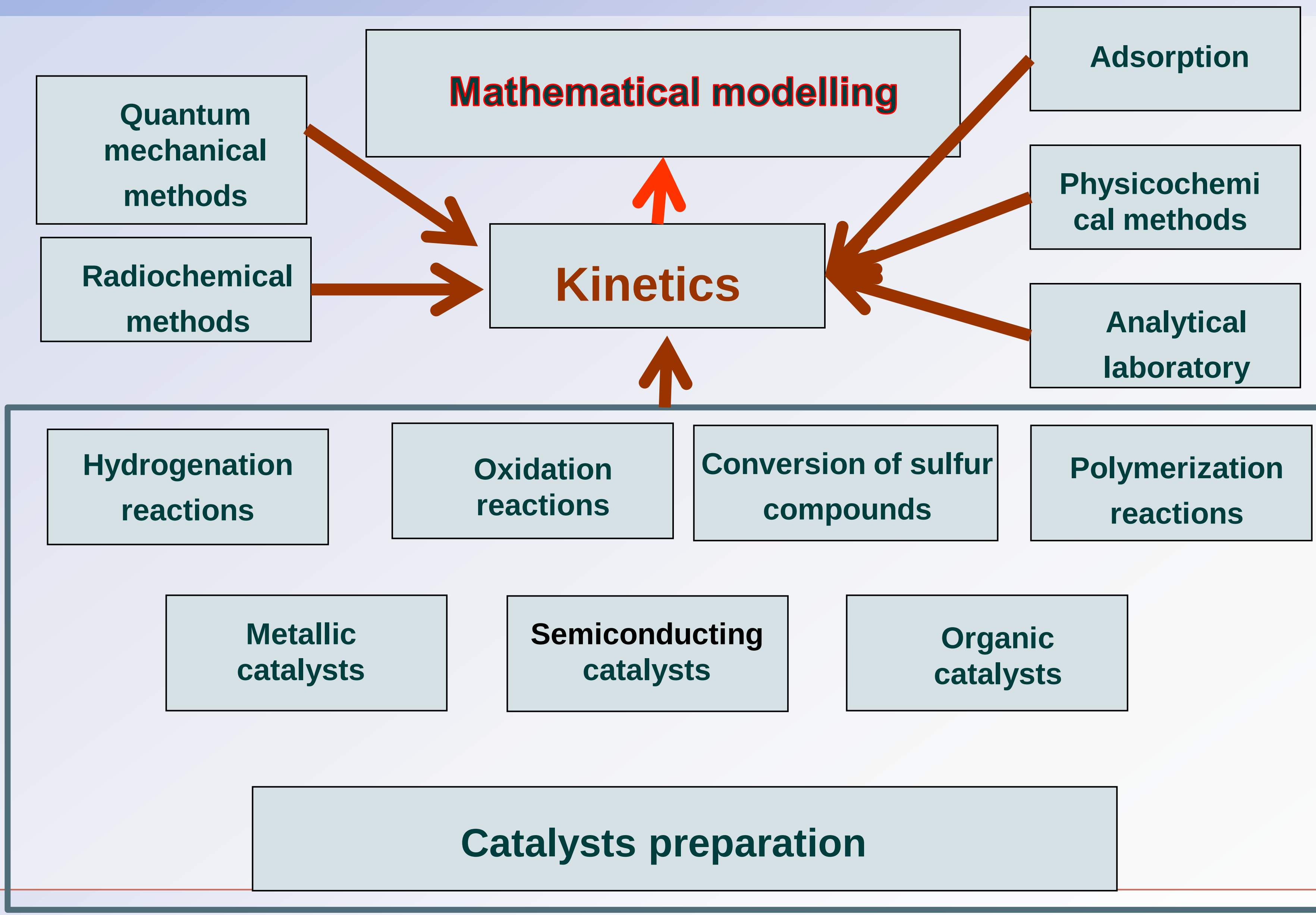
The unity of a theory and application

The development of the theory and practice of the catalyst preparation with the given structure, selectivity and activity.

The detailed study of the mechanism of reactions and kinetic studies.

Mathematical modelling of heterogeneous catalytic reactions, processes and reactors on the basis of the detailed mechanism and kinetics

The structure of Institute of Catalysis 1963



The first collaboration between USSR and a West Europe (UCB from Belgium) on Chemical Engineering

1965

The development and the improvement of the catalyst and reactor design for acrylonitrile production via Sohio method

$$C_3H_6 + NH_3 + 1.5\ O_2 \rightarrow C_3H_3N + 3H_2O + 520\ dj/mole$$

N. Stas, M. Slinko, J. Vekemans, Veraiden

1969 For this work and successful collaboration with the UCB firm the Institute of catalysis was awarded by Order of Red Banner of Labor

Yield increase from 54 to 66-70% with the increase of the intensity of the process from 35 to 75 of gr NAK/kg catal. was achieved

The study of stability at different levels of a chemical process

1961-1972

Stability of a process over one pellet
T.I. Zelenjak, V.S. Beskov, M.G. Slinko Kinetika and Catalysis, v.7, 1966, 865

Stability of a reactor with not well mixed bed
E.A. Ivanov, V.S. Beskov, M.G. Slinko, Theoretical foundations of chemical engineering 1, 1967, 488

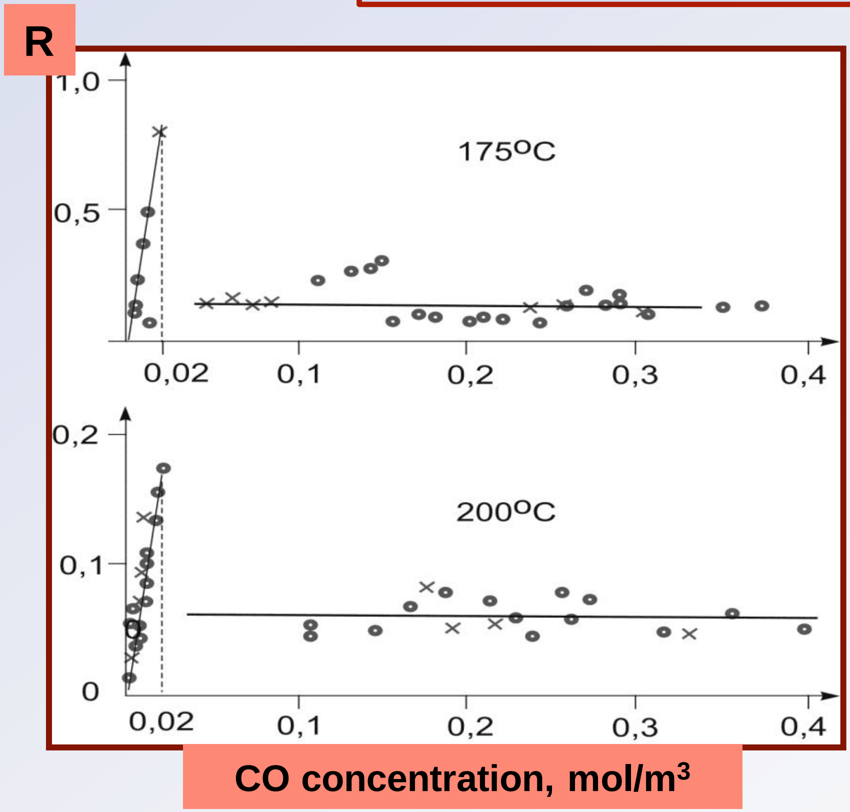
Stability of a reactor with an external heat exchanger
M.G. Slinko, A.L. Muller, Kinetika and Catalysis, v.2, 1961, 467

Stability of chemical-engineering schemes
Yu. M. Volin, G.M. Ostrovskii, M.G. Slinko, Theoretical foundations of chemical engineering 6, 1972, 109

1971

First publication about the multiplicity of steady states in kinetic region

$$CO + 3H_2 = CH_4 + H_2O$$



1. $CO + [Ni] \leftrightarrow [Ni\text{-}CO]$
2. $3H_2 + 6[Ni] \leftrightarrow 6[Ni\text{-}H]$
3. $6[Ni\text{-}H] + [Ni\text{-}CO] \rightarrow CH_4 + H_2O + [Ni]$

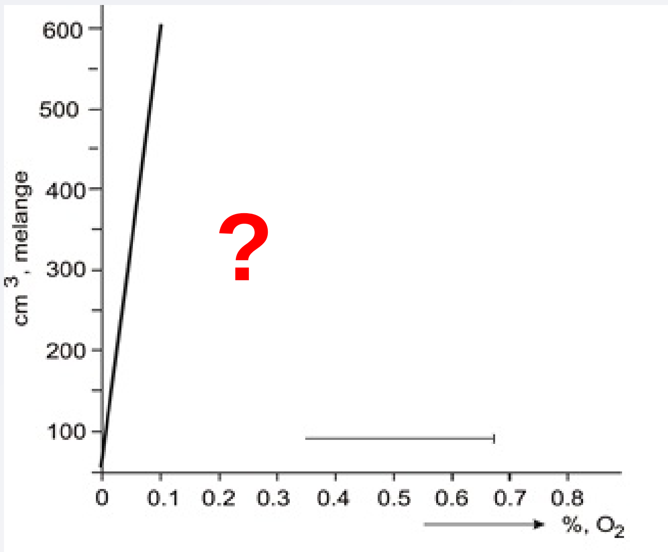
$$E_3 = E_{30} + RT\ \mu\theta_{CO}$$

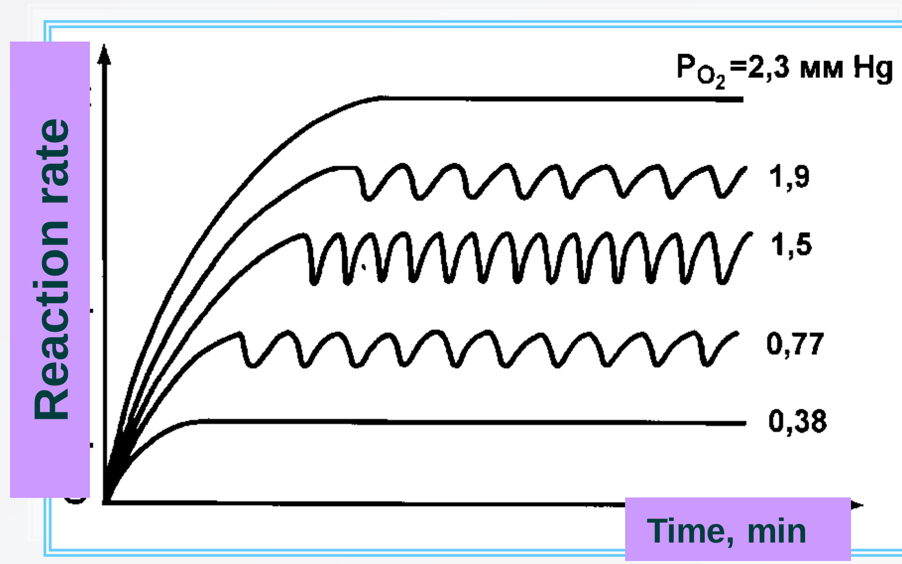
The first mathematical model, describing multiplicity of steady states was suggested

M.G. Slinko, V.S. Beskov, I.A. Dubjaga, Dokl. AN USSR, 204, 1972, 1174

The discovery of oscillations during hydrogen oxidation over Ni

1972





Beusch, H.; Fieguth, D.; Wicke, E. *Chem. Eng. Tech.* 1972, 44, 445

Belyaev V.D., Slinko M.M., Timoshenko V.I., M.G. Slinko . „Onset of Oscillations in Hydrogen Oxidation on Nickel„ Kinetics and Catalysis, 1973, 17, 810

The first mathematical model, producing the oscillations in heterogeneous catalytic systems

1973

$$O_2 + 2[Ni] \rightleftarrows 2[OH] \qquad x = [ONi]$$

$$H_2 + 2[Ni] \rightleftarrows 2[ONi] \qquad y = [HNi]$$

$$[ONi] + 2[HNi] \xrightarrow{k_3} H_2O + 3[Ni]$$

$$\frac{dx}{dt} = k_1(1-x-y)^2 - k_{-1}x^2 - k_3xy^2e^{-\mu x}$$

$$\frac{dy}{dt} = k_2(1-x-y)^2 - k_{-2}x^2 - k_3xy^2e^{-\mu x}$$

$$\boxed{E_3 = E_{30} + \mu x} \qquad \boxed{k_3 = k_{30}e^{-\mu x}}$$

First Mathematical Model of Chaotic Oscillations in Heterogeneous Catalytic Systems

1980

G. Chumakov, M. Slinko, V. Belyaev

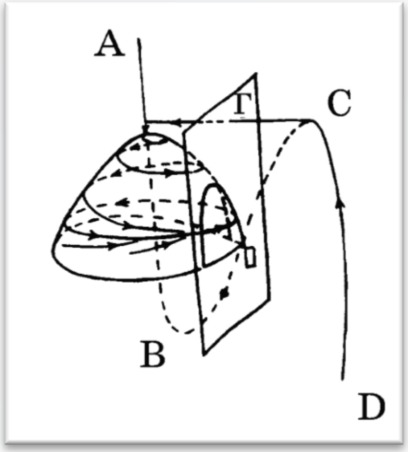
$$H_2 + 2[Ni] \underset{k_{-1}}{\overset{k_1}{\rightleftarrows}} 2[HNi] \qquad x = [HNi]$$

$$O_2 + 2[Ni] \underset{k_{-2}}{\overset{k_2}{\rightleftarrows}} 2[ONi] \qquad y = [ONi]$$

$$[ONi] + 2[HNi] \xrightarrow{k_3} H_2O + 3[Ni]$$

$$H_2 + [ONi] \xrightarrow{k_4} H_2O + [Ni]$$

$$[ONi] + [Ni_v] \underset{k_{-5}}{\overset{k_5}{\rightleftarrows}} [Ni] + [ONi_v] \qquad z = [ONi_v]$$



$$k_3 = k_{30} e^{-\mu_3 y}, \qquad k_4 = k_{40} e^{-\mu_4 y - \mu_5 z}$$

G.A. Chumakov, M.G.Slinko, V.D. Beljaev, Dokl. AN USSR, 253, 1980, 653
G.A. Chumakov, M.G.Slinko, Dokl. AN USSR, 266, 1982,1193

Scientific cooperation between the USA and the USSR 1974-1980

M.G.Slinko coordinated the *US-USSR* exchange program in mathematical modelling of chemical reactors and processes

Prof. M.G.Slinko and Prof. Dan Luss in Novosibirsk, 1974

Prof.Ray, Dr.Vjatkin, Dr.Bykov, Dr.Akramov, Prof.Luss, Dr.Chumachenko, Dr.Yablonski, Prof.Aris

Isothermal sustained oscillations due to the influence of adsorbed species on the catalytic reaction rate

E.A. Ivanov, G.A. Chumakov, M.G. Slinko, D.D. Bruns, D. Luss//Chemical Engineering Science 35 (4), 795-803, 1980

Number and stability of the steady states of 4-stage reactions

G.A. Chumakov,V.D.Belyaev, R. Plikhta, V.I. Timoshenko, M.G. Slinko//Doklads Russian Academy of Sciences 253 (2), 418, 1980

Department of mathematical modelling M.G.Slinko

1975

Processes in a fluidized bed
Sheplev V.S.

Kinetics of catalytic reactions
Timoshenko V.I.

Phase transitions
Shmelev A.S.

Liquid phase processes
Ermakova A.

Unsteady state processes and Stability
Matros Yu.Sh.

Complex processes
Kuznetsov Yu.I.

Numerical methods
Gaevoi V.P.

Qualitative methods
Ivanov E.A.

Computer engineering
Scomorochov V.B.

Return to Moscow to Karpov Institute

1976

More than 450 papers on different topics had been written scince 1976

Kinetics

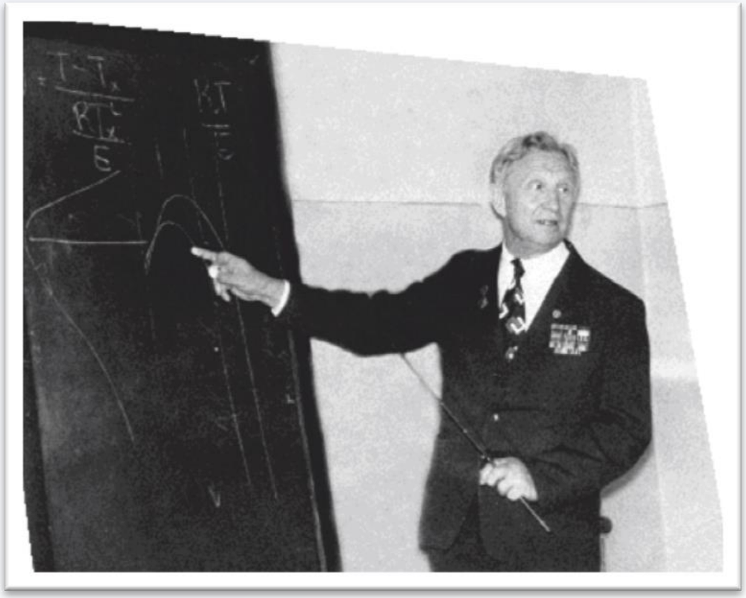
A method to study reaction kinetics over finely-dispersed catalyst in stationary and nonstationary conditions

Membrane catalysis

Selectivity in catalysis by hydrogen porous membranes

Processes

Crystallization
Copolymerization
Distillation
Evaporation of aerosols
Ethylene oxide production
Hydrocarbon hydrogenation
Processes with changing of the catalyst activity
Production of synthetic liquid fuels from coal



Dynamics

Modelling of chaotic oscillations
Calculation of Lyapunov coefficients by analysis of self-sustained oscillations
Study of the relaxation of a reaction rate over various kinds of catalytic surface

Reactors

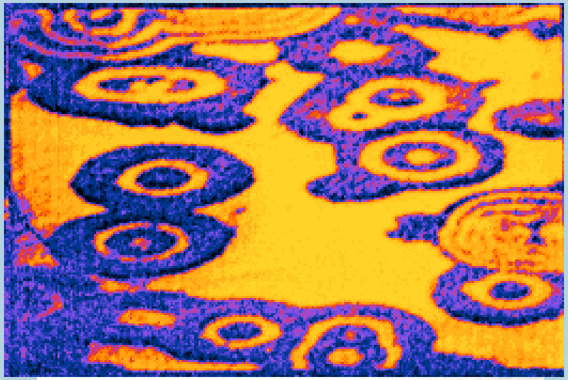
Fixed *bed r*eactors
Three-phase systems
Ascending catalyst flow
Fluidized bed reactors
Chromatographic reactors

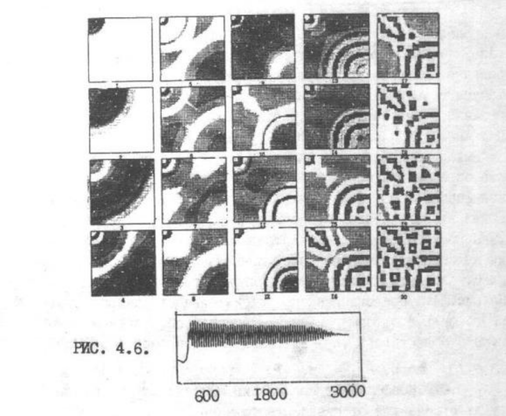
Makrokinetics

Gel-immobilised catalytic systems
On the interfacial exchange at the surface convective structures in a liquid

Mathematical modelling at the micro- and mezo-levels 1986- 1994

Mathematical simulation of catalytic processes has to begin at the micro- and mezzo-levels. Transition from micro-level to mezo-level





The development of distributed nonlinear models based on cooperative interactions and mobility of adsorbed species

$$R_i = k_i \theta_p I_a$$

$$I_a = \left[\theta_* + \sum_{1}^{p} \theta_p \exp(\varepsilon_{ap} / RT) \right]^m$$

θ_* coverage of vacant sites

m – number of nearest neighbor sites

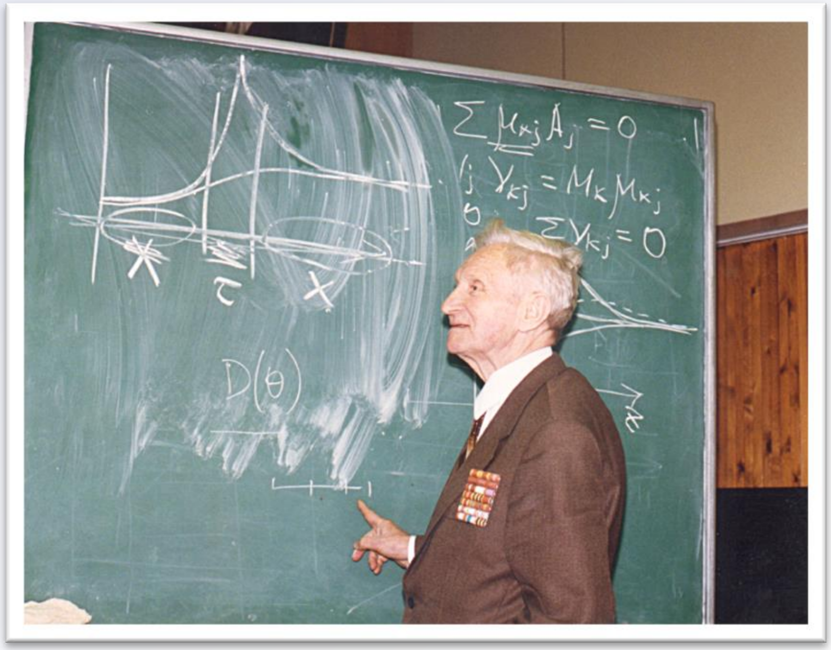
ε – energy of lateral interactions

M.G.Slinko, G.G.Elenin “Mathematical Modelling of Phenomena on a Surface”, Russian Chemistry Industry, 1991, N4, p.243

Last paper, written one month before death

2008

M. G. Slinko " To the 100 Anniversary of Professor M.I.Temkin. The Founder of Chemical Kinetics" catalysis in Industry, N5, 2008, 5



Memories about Husband, Father, Grandfather and Great-grandfather

Thank you for your attention!