Российская академия наук

ГАЗОГИДРАТЫ: теплофизика и технологии

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18 Международная конференция
ГЕОЛОГИЯ МОРЕЙ и ОКЕАНОВ
Институт океанологии им П.П. Ширшова РАН
Российский фонд фундаментальных исследований
ФГУНП «СЕВМОРГЕО»
16-20 ноября 2009

Международная конференция
ПЕРСПЕКТИВЫ ОСВОЕНИЯ ГАЗОГИДРАТНЫХ МЕСТОРОЖДЕНИЙ
РГУ нефти и газа им. И.М. Губкина, Москва
17-18 Ноября 2009

Russian Academy of Sciences

GAS-HYDRATES: Thermophysics & Technologies

Robert Nigmatuin
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Birsk University

XVIII International Conference
MARINE and OCEAN GEOLOGY
P.P. Shirsov Institute of Oceanology, Moscow
Russian Foudation of Fundamental Research
FSUE “SEVMORGEO”
November 16-20, 2009

International conference
GAS HYDRATES RESOURCES DEVELOPMENT
Gubkin Russian State University of Oil and Gas, Moscow
17-18 November 2009

Уразов Руслан Рубикович

Моделирование образования газовых гидратов в трубопроводе

Уфимский государственный авиационный технический университет, РФ

Мусакаев Наиль Габсалямович

Численная модель образования газогидрата в пористой среде при инжекции газа

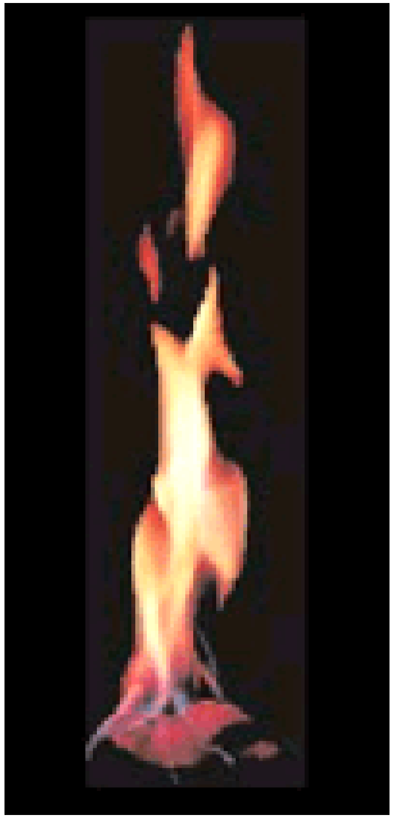
Тюменский филиал Института теоретической и прикладной механики им. С.А. Христиановича СО РАН РФ

Чиглинцева Ангелина Сергеевна

Анализ возможных способов добычи газа из газогидратных месторождений

Бирская государственная социально-педагогическая академия, РФ

Methane Gas-Hydrates

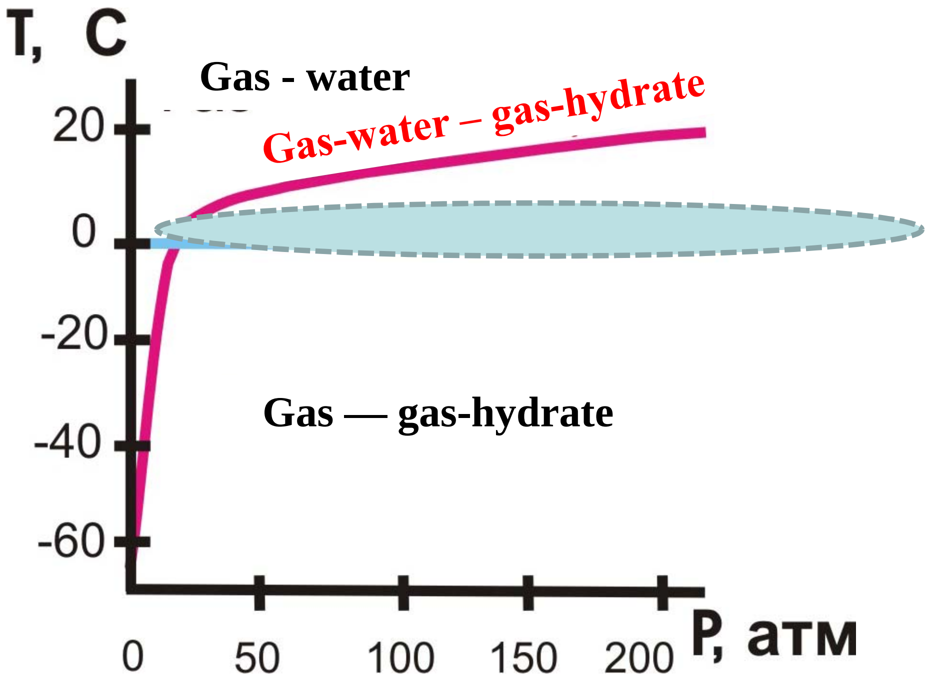


$$c_h^{\circ} = 900\,\mathrm{kg/m^3};$$

The mass contents of methane $G = 0{,}12$

Specific heat of decomposition $l = 5\times10^5\,\mathrm{m^2/s^2}$

(melting heat of water ice $l \approx 3\times10^5\,\mathrm{m^2/s^2}$)



Gas-Hydrate State for the Gas Storage

Mass of the Gas (Methane) in V_0 = 1 m^3

$$M = c_h^\circ G = 900 \times 0{,}11 \approx 100\,\text{kg}$$

Volume of this Gas at the Normal conditions:

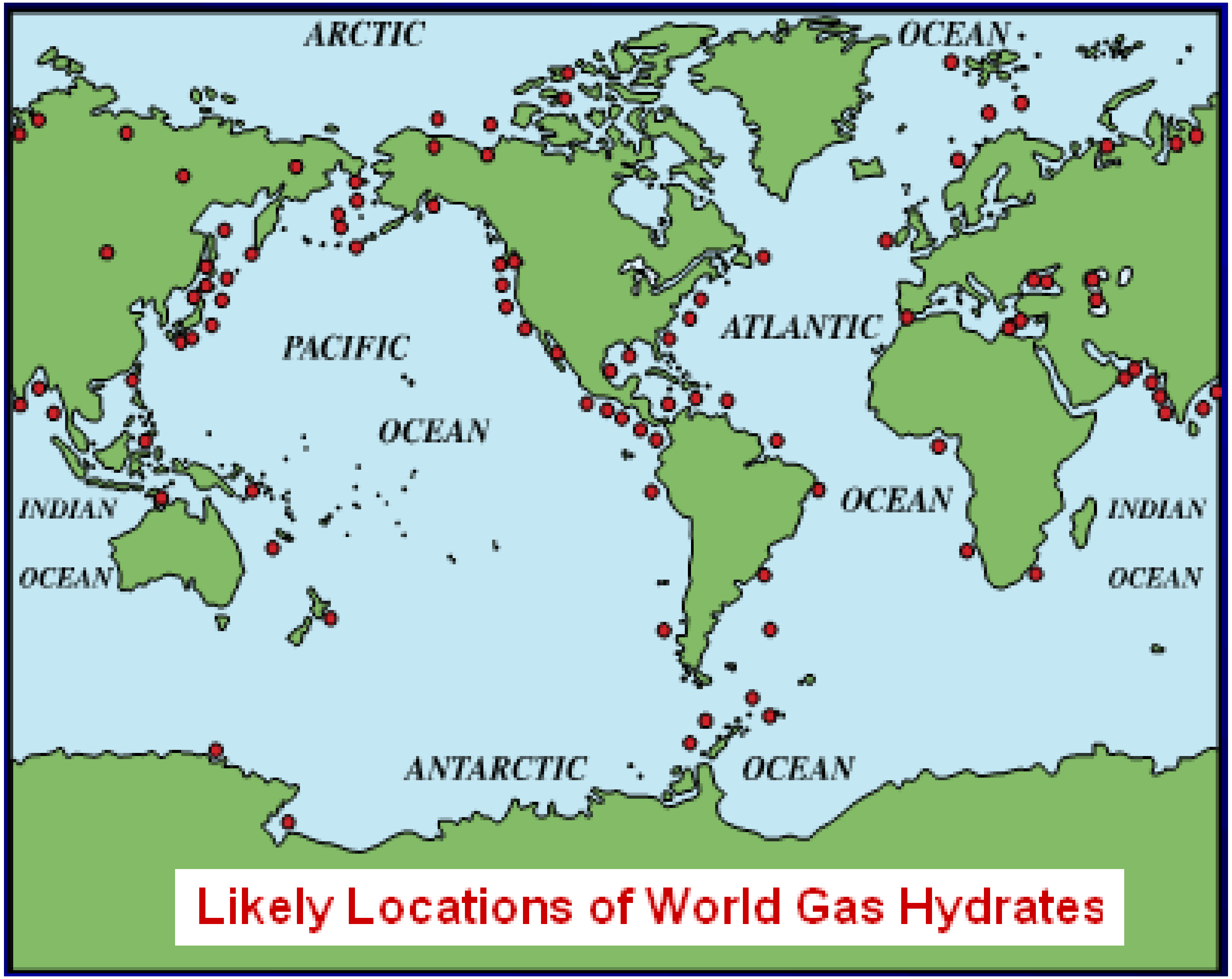
T = 273 K, p = 1 bar, $\rho_g^\circ = 0{,}7\,\text{kg/m}^3$

$$V = \frac{M}{c_g^\circ} \approx 150\,\text{m}^3$$

In the Gas Tank by V_0 = 1 m^3 **p ≈ 200 bar**

In Gas-Hydrate state (GH-Tank) by V_0 = 1 m^3 p ≈ 25 bar

Fulerens: **C_{60} , $C_{60}H_{60}$** !!!



ARCTIC
OCEAN
PACIFIC
OCEAN
ATLANTIC
OCEAN
INDIAN
OCEAN
INDIAN
OCEAN
ANTARCTIC
OCEAN
Likely Locations of World Gas Hydrates

Alaska(USA) Norway

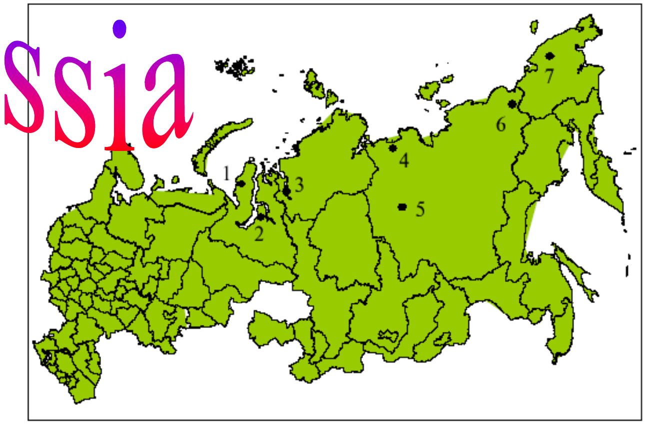
Great Britain

Gas hydrates

Africa

Germany

Russia



India

South Korea

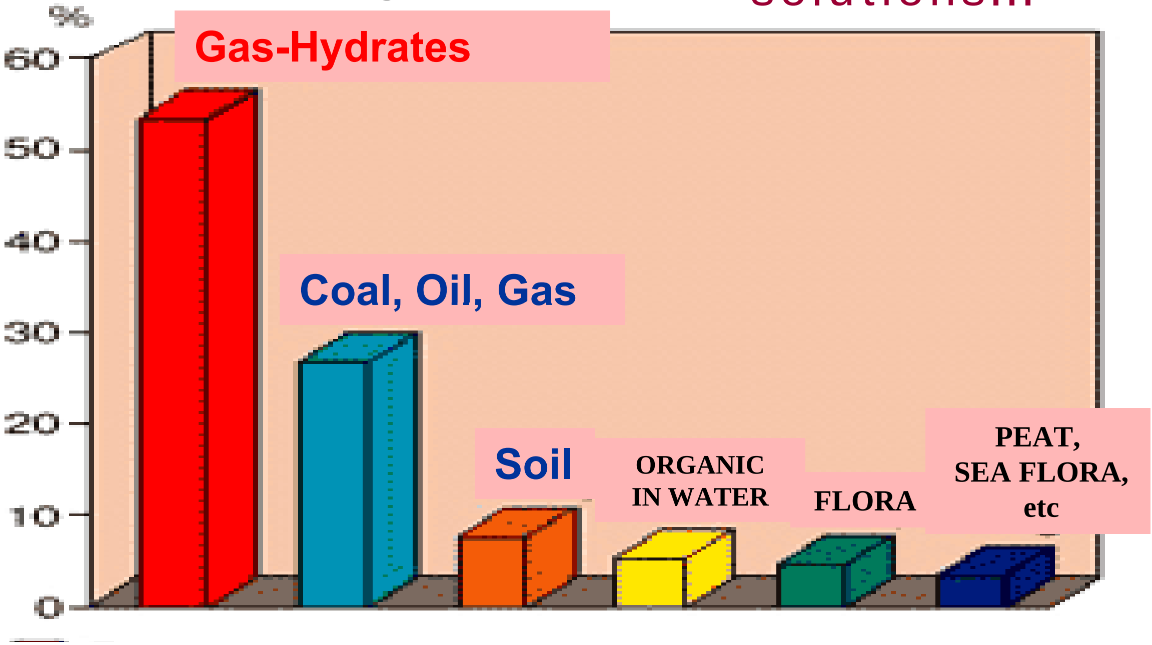
Canada

China

Japan

...Gas-Hydrate is a very large potential resource, it just needs some very bright people with new ideas to find the solutions...

Distribution of organic carbon



Underground Gas-Hydrate Resources:

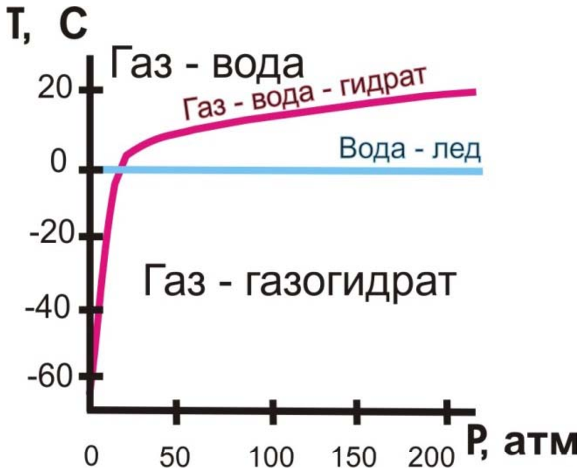
15 – 35 000 Tm^3

Marine Gas-Hydrate Resources:

30 000 – 8 000 000 TM^3 ???

Mineral Gas Resources *V* = 200 Tm^3

The Transition Temperature for the Methane Gas-Hydrate on Pressure



Temperature Reserve of a Porous Medium to extract the Gas from the Gas-Hydrate

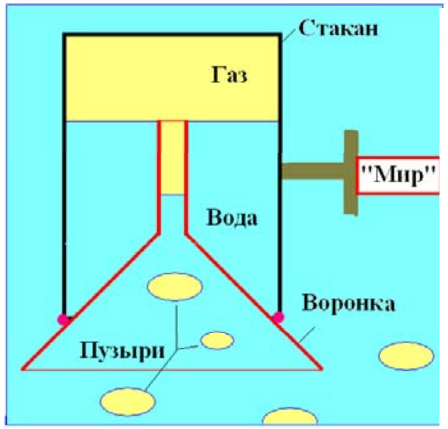
$$\Delta T = \frac{m\, c_h^0\, l}{\rho c} \approx 25\mathrm{K}$$ even for m = 0,1 (porosity)

$$\rho c \approx 2 \times 10^6 \ \mathrm{J/m^3\,K}$$

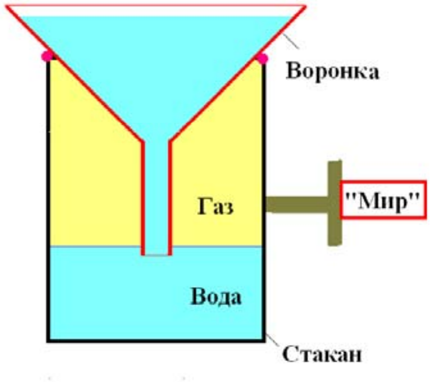
Heat Capacity per volume unit of «Gas-Hydrate – Skeleton» Porous System

Only by depression we can not to extract the Gas.
HEATING !!!

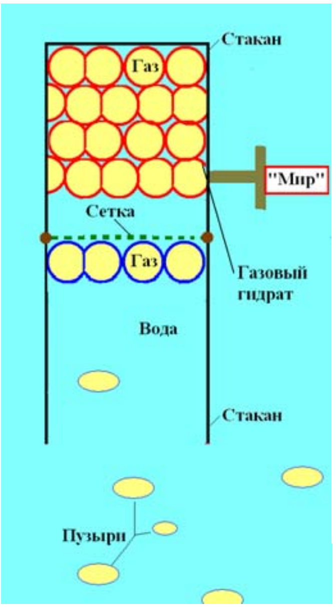
BAYKAL - 2009

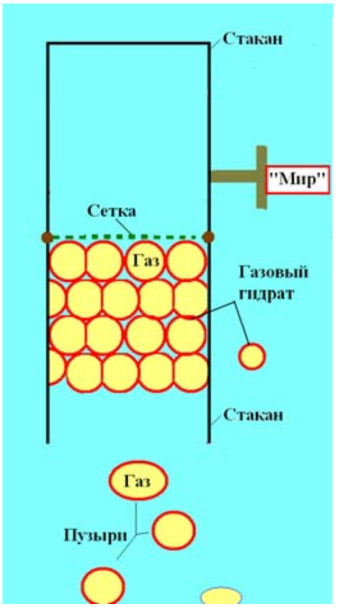


При отборе газа воронка обращена ко дну водоёма

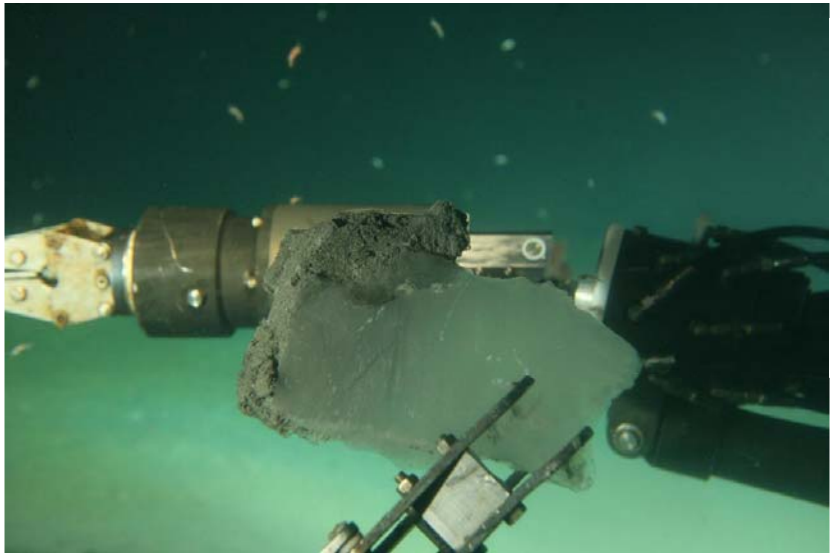


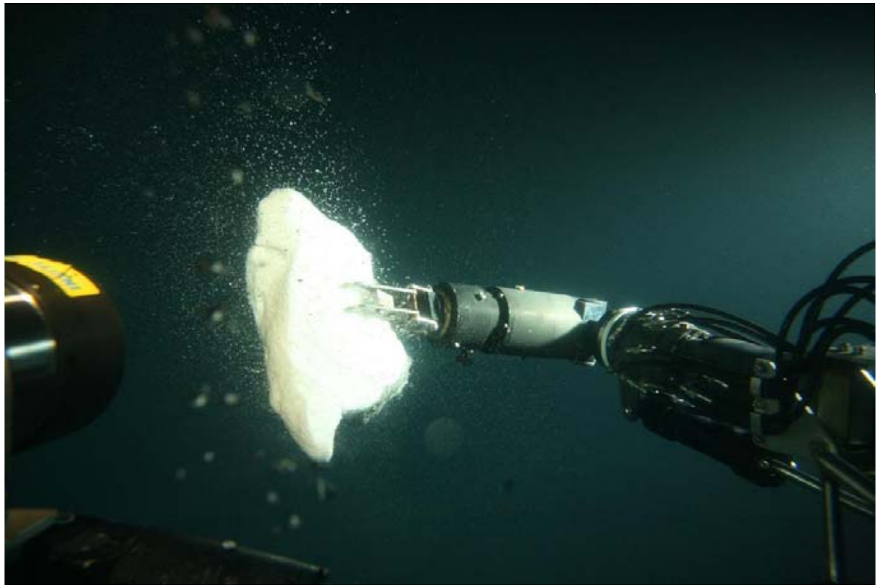
При подъёме на борт воронка обращена к небу





BAYKAL - 2009





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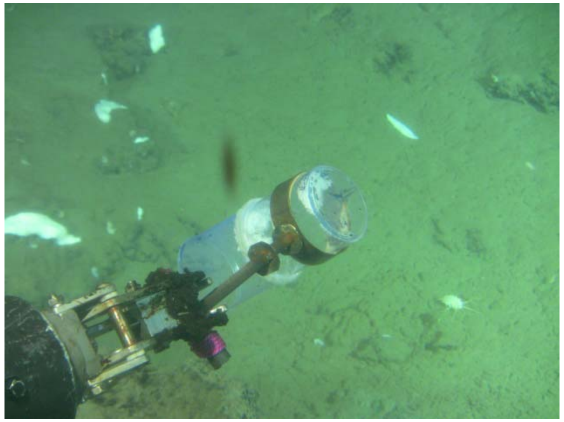
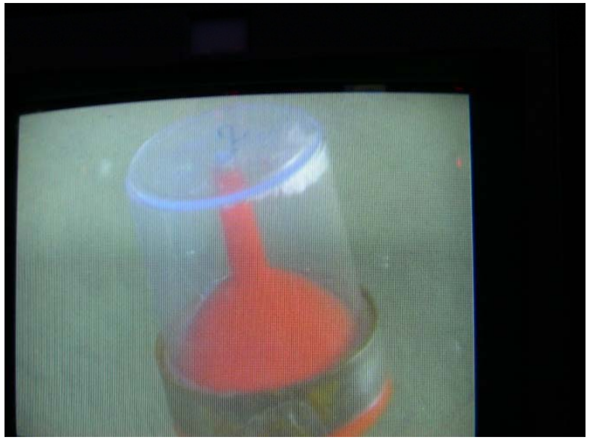
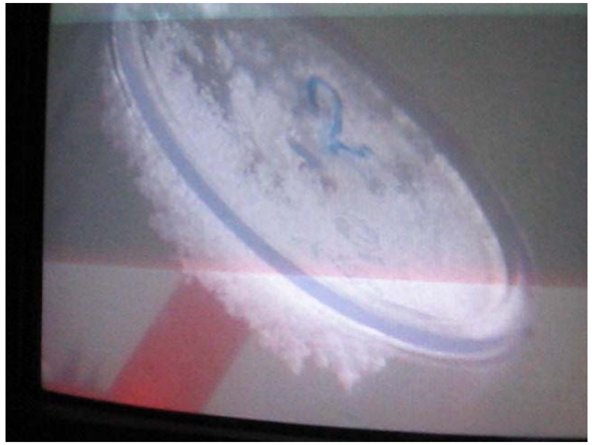
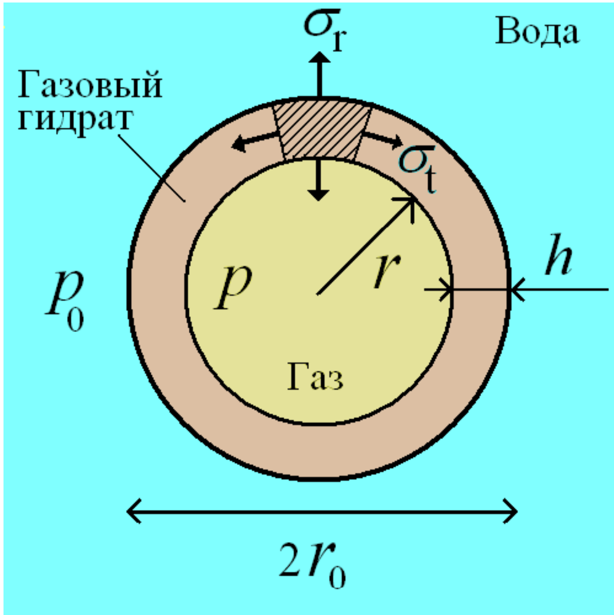
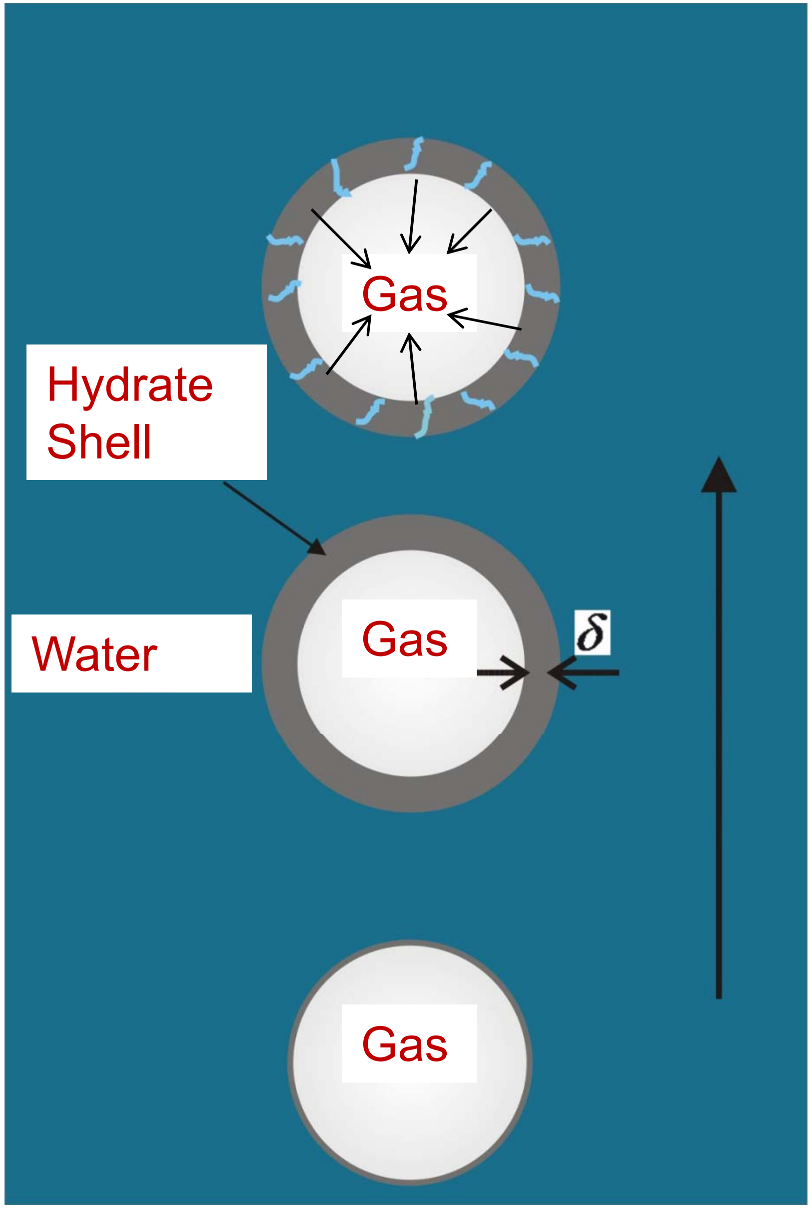


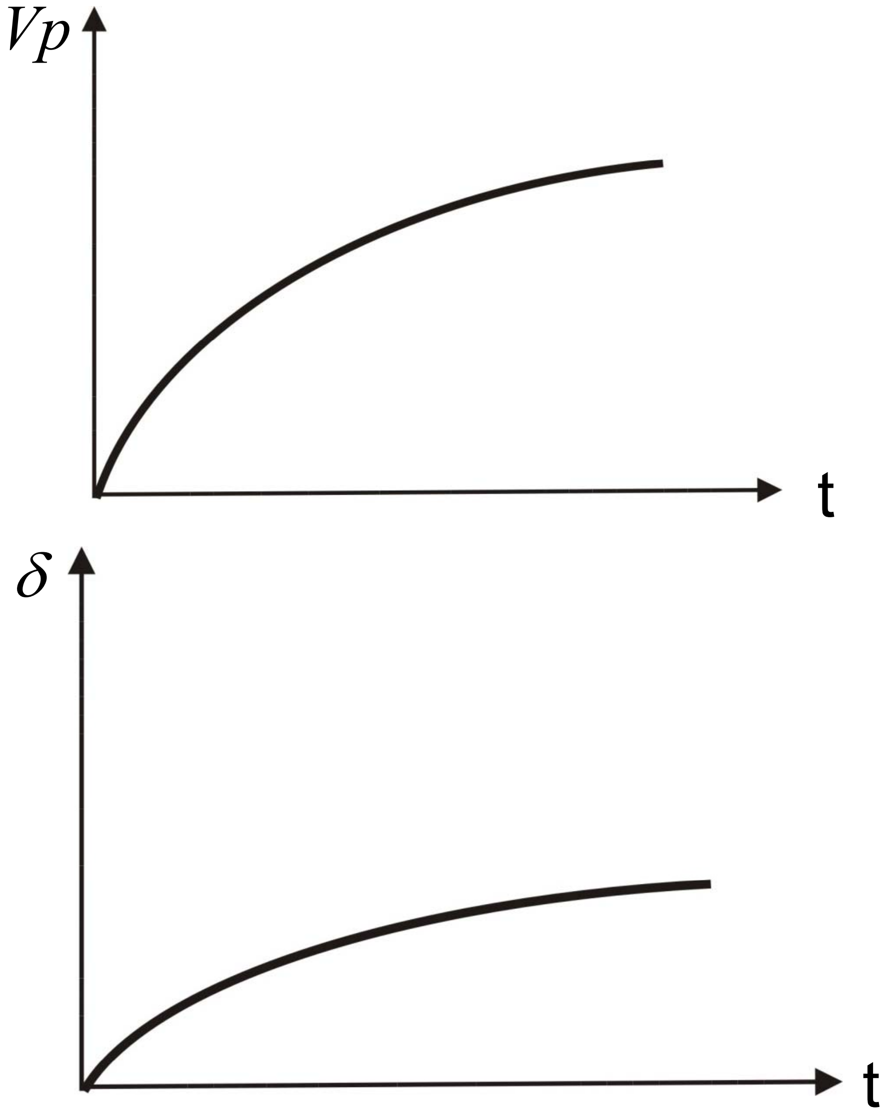






“Пыньк-эффект” – “PYANK-effect”- Implosion

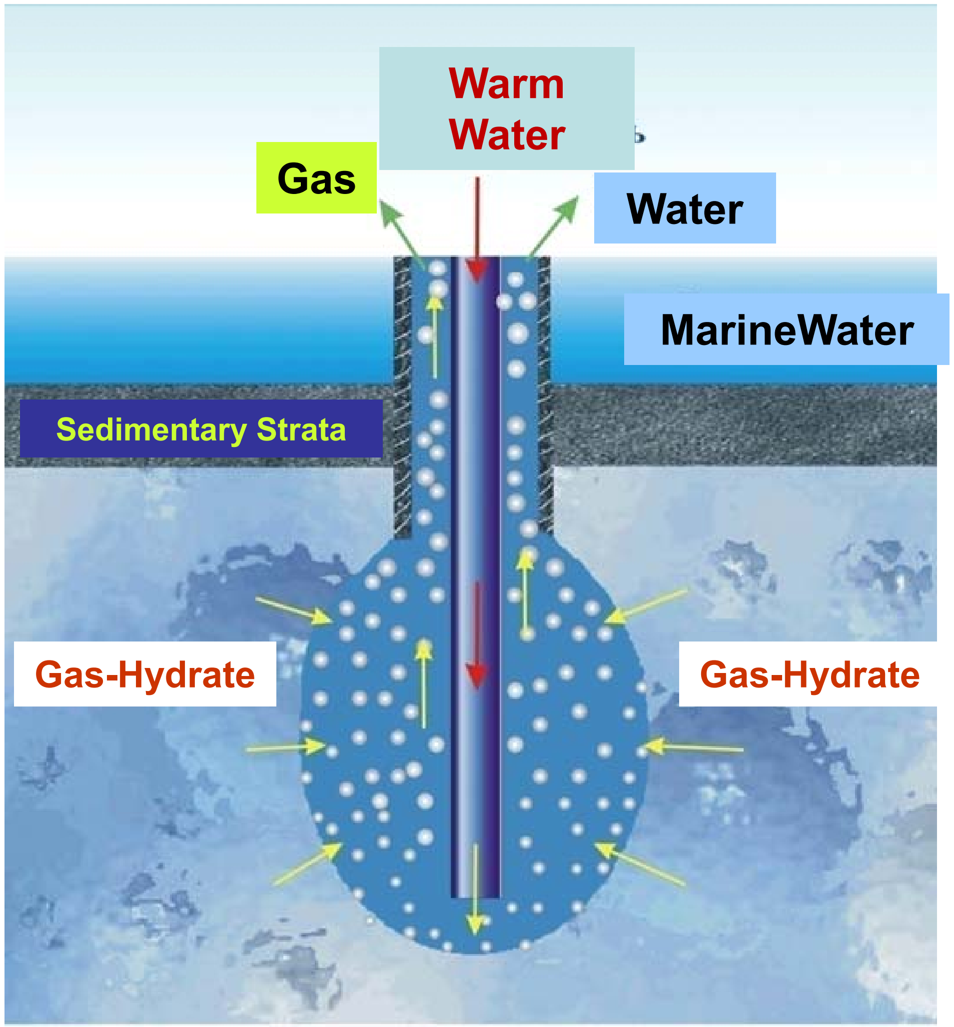




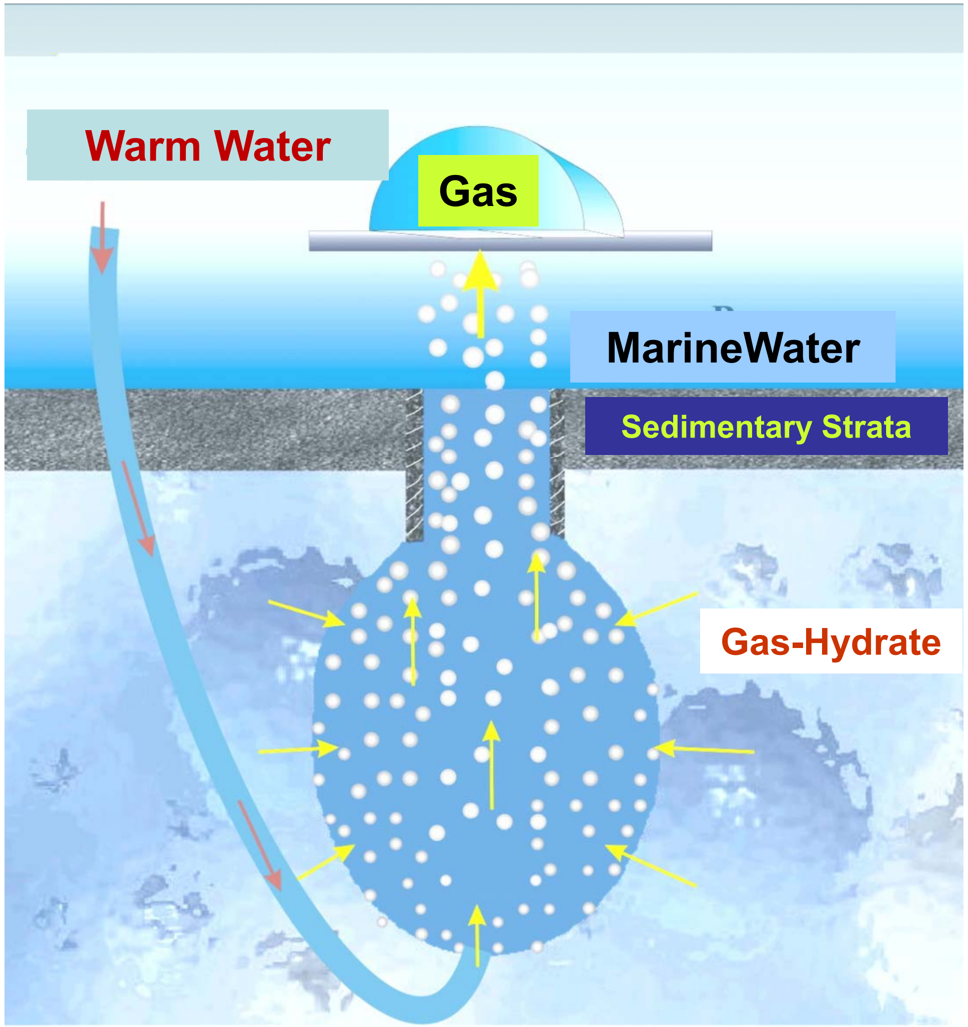
$$Vp = p_l - p_g$$

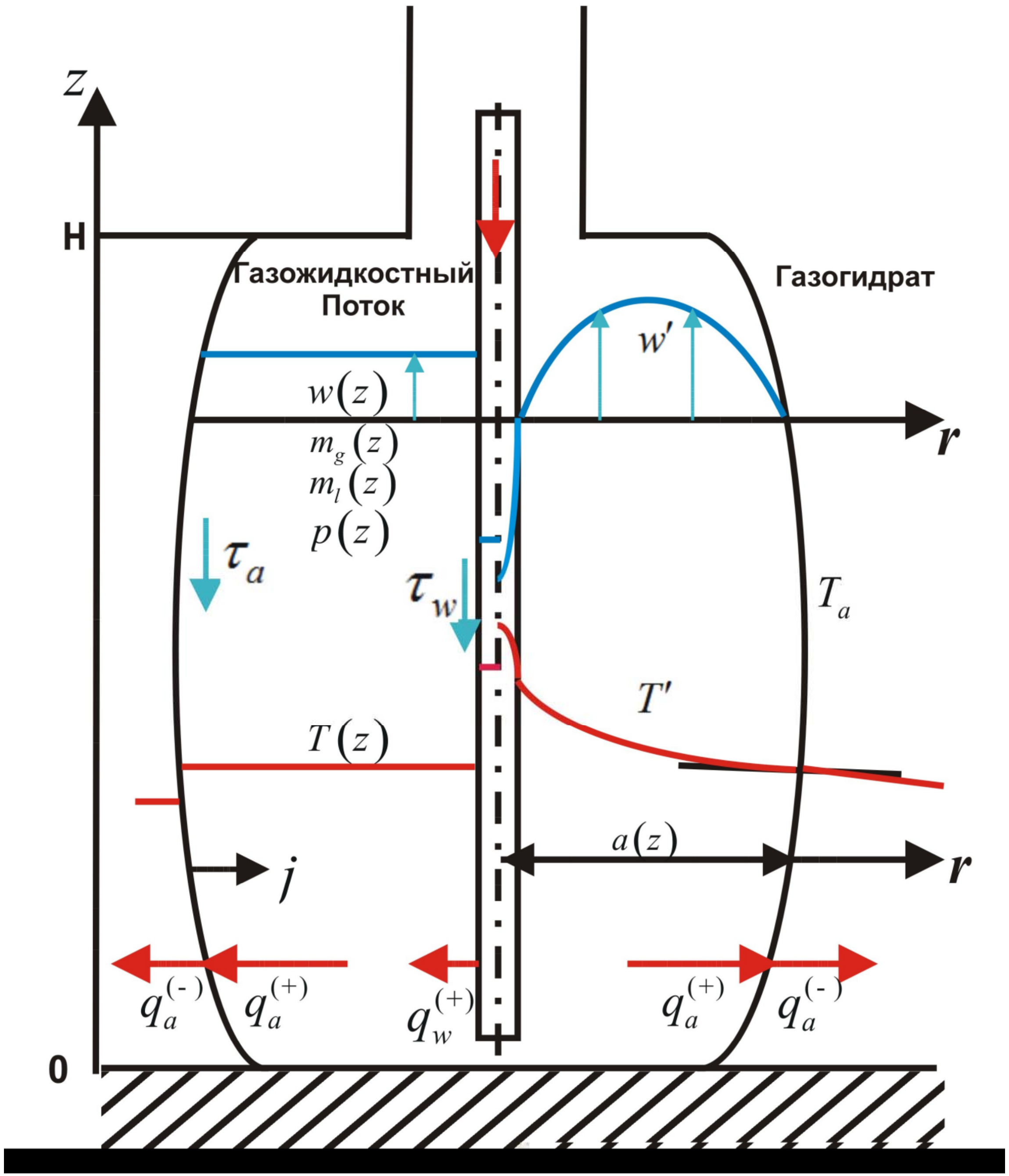
Warm Water Technologies

a)



b)





z
H
0
Газожидкостный Поток
Газогидрат
w'
$w(z)$
r
$m_g(z)$
$m_l(z)$
$p(z)$
τ_a
τ_w
T_a
T'
$T(z)$
$a(z)$
j
r
$q_a^{(-)}$
$q_a^{(+)}$
$q_w^{(+)}$
$q_a^{(+)}$
$q_a^{(-)}$

Mathematical Modelling

For products of washout

Equations of weights for liquid and gas phases

$$\frac{\mathrm{d}m_i}{\mathrm{d}z} = 2\mathrm{p}a\, j_i, \quad m_i = Swc_i^\circ б_i, \quad (i = g, l)$$

$$j_g = Gj,\ j_l = (1-G)\,j, \qquad \left(\alpha_g + \alpha_l = 1,\ S = \pi\left(a^2 - a_c^{(+)2}\right)\right)$$

Momentum equation

$$m\frac{dw}{dz} = -S\frac{\mathrm{d}p}{\mathrm{d}z} - S\mathrm{c}g - 2\mathrm{p}a\tau - 2\mathrm{p}a_c^{(+)}ф_c^{(+)} - 2\mathrm{p}ajw,$$

$$\left(m = m_g + m_l,\ \rho = \rho_g^0\alpha_g + \rho_l^0\alpha_l\right)$$

Heat flux equation

$$\left(m_g c_g + m_l c_l\right)\frac{\mathrm{d}T}{\mathrm{d}z} = \frac{m_g}{\rho_g^\circ}\frac{\mathrm{d}p}{\mathrm{d}z} + 2\pi ajc\left(T_a - T\right) + 2\pi a q_a^{(-)}$$

$$+ 2\pi a_w q_w^{(+)},$$

$$\left(c = c_g G + c_l\left(1-G\right)\right)$$

State equations

$$\mathrm{c}_l^\circ = \mathrm{const}, \qquad p = \rho_g^0 R_g T$$

For injected warm water

$$\frac{\mathrm{d}p^{(i)}}{\mathrm{d}z} = -\rho_l^0 g + \frac{2\tau_c^{(-)}}{a_c^{(-)}},$$

$$m_l^{(-)} c_l \frac{\mathrm{d}T^{(i)}}{\mathrm{d}z} = 2\pi a_c^{(-)} q_c^{(-)},$$

$$\left(m_l^{(i)} = \pi a_c^{(-)2} w^{(i)} \rho_l^0\right)$$

$p^{(i)}$ - pressure in a tube,

$a_c^{(-)}$ - internal radius of a tube,

$\tau_c^{(-)}$ - Force of hydraulic friction between a flow and wall, referred to unit of its area,

$m_l^{(i)}, T^{(i)}, w^{(i)}$ - Temperature, mass flow, speed of water

$q_c^{(-)}$ - Heat-transfer intensity referred to a unit area of a wall of a tube.

Power and thermal interactions

For injected water

$$\tau_c^{(-)} = \xi_c^{(-)} \frac{\rho_l^0 w^{(i)2}}{8}, \qquad \xi_c^{(-)} = \left(1.82\lg \mathrm{Re}_l - 1.64\right)^{-2}, \qquad q_c^{(-)} = \beta_c^{(-)}\left(T^{(i)} - T_c^{(-)}\right), \qquad \beta_c^{(-)} = \frac{\lambda_l \mathrm{Nu}_l^-}{2a_c^{(-)}},$$

$$\mathrm{Nu}_l^- = \frac{\left(\xi_c^{(-)}/8\right)\mathrm{Re}_l \mathrm{Pr}_l}{1.07 + 12.7\sqrt{\xi_c^{(-)}/8}\left(\mathrm{Pr}_l^{2/3} - 1\right)}, \qquad \mathrm{Pr}_l = \frac{\mu_l c_l}{\lambda_l}, \qquad \mathrm{Re}_l = \frac{2a_c^{(-)}\rho_l w_l}{\mu_l}$$

For products of washing

$$\tau_c^{(+)} = \tau = \xi \frac{\rho w^2}{8}, \qquad \xi = \left(1.82\lg \mathrm{Re} - 1.64\right)^{-2}, \qquad q_c^{(-)} = q_c = q_c^{(+)} = \beta(T^{(i)} - T), \qquad q^{(-)} = \beta^{(-)}\left(T_a - T\right), \qquad \beta_c = \frac{\lambda_c}{\Delta a_c}, \qquad \mathrm{Pr} = \frac{\mu c}{\lambda}$$

$$\mathrm{Nu} = \frac{(\xi/8)\mathrm{Re}\,\mathrm{Pr}}{1.07 + 12.7\sqrt{\xi/8}\left(\mathrm{Pr}^{2/3} - 1\right)}, \qquad \mathrm{Re} = \frac{2\left(a - a_c^{(+)}\right)\rho w}{\mu}, \qquad \frac{1}{\beta} = \frac{1}{\beta_c^{(-)}} + \frac{1}{\beta_c} + \frac{1}{\beta_c^{(+)}}, \qquad \beta_c^{(+)} = \frac{\lambda\,\mathrm{Nu}}{2\left(a - a_c^{(+)}\right)}, \qquad \beta^{(-)} = \frac{\lambda \mathrm{Nu}}{2(a - a_c^{(+)})}$$

Dependence of temperature of a wall in working face from pressure

$$T_a = T_s(p), \qquad T_{(s)}(p) = T_{(h0)} + T_* \ln(p/p_{(h0)})$$

Intensity of a the Liquid and Gas Production

$$j = \frac{q^{(-)} - q^{(+)}}{l_h}, \qquad q^{(+)} = -\lambda_h \left(\frac{\partial T_h}{\partial r}\right)_a$$

Evolution of the temperature field in the solid gas-hydrates stratum

$$\left(\left|\partial T_h/\partial r\right| ? \left|\partial T_h/\partial z\right|\right)$$

Thermal conduction in

a gas-hydrate stratum

$$\rho_h^0 c_h \frac{\partial T_h}{\partial t} = \lambda_h r^{-1} \frac{\partial}{\partial r}\left(r \frac{\partial T_h}{\partial r}\right), \quad (a < r < \infty)$$

Boundary condition

$$T_h = T_a, \ (r = a) \quad \text{и} \quad T = T_{h0}, \ (r = \infty)$$

The approximation of temperature around the bag

$$T_h = \frac{(T_{h0} - T_a)}{a_* - a - a_* \ln(a_*/a)}\left(r - a - a_* \ln(r/a)\right) + T_a$$

Satisfying the conditions

$$T_h = T_a, \ (r = a) \quad \text{и} \quad T_h = T_{h0}, \ \frac{\partial T_h}{\partial r} = 0, \ (r = a_*)$$

From the equation of a heat balance

$$\frac{\partial}{\partial t}\int_a^{a_*} 2\pi r c_h \rho_h^0 \left(T_h - T_{h0}\right) dr = -2\pi a \lambda_h \left(\frac{\partial T}{\partial r}\right)\Bigg|_{r=a} \quad a < r < a_*$$

We'll receive an equation for radius of thermal influencing

$$\frac{\partial}{\partial t}\frac{6a_*^3 \ln(a_*/a) - 3a_*\left(a_*^2 - a^2\right) - 4\left(a_*^3 - a^3\right) + 6a\left(a_*^2 - a^2\right)}{a_* - a - a_* \ln(a_*/a)} = -12\nu_h \frac{a_* - a}{a_* - a - a_* \ln(a_*/a)}$$

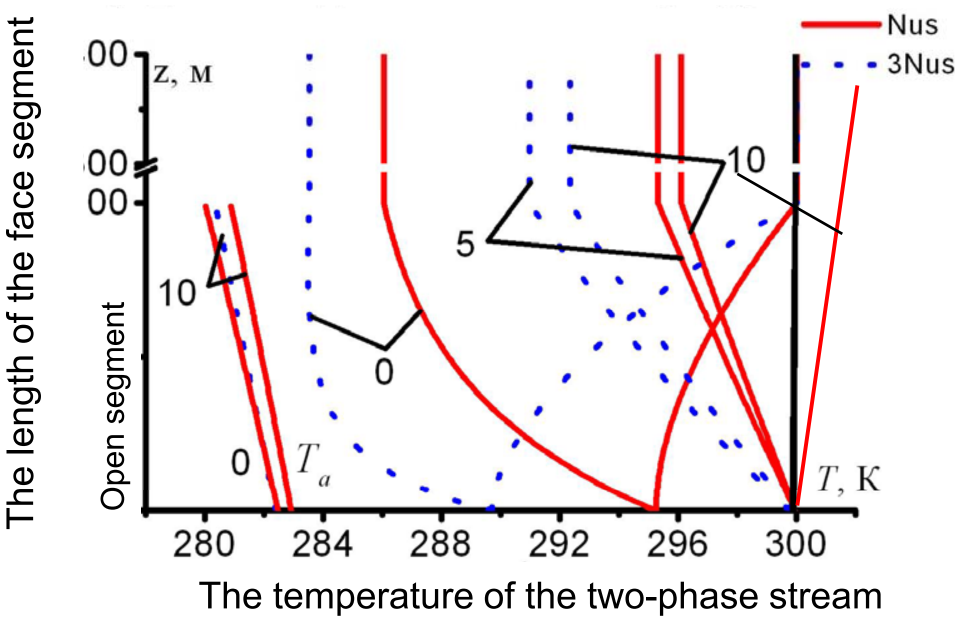
Evolution of radius of the bag

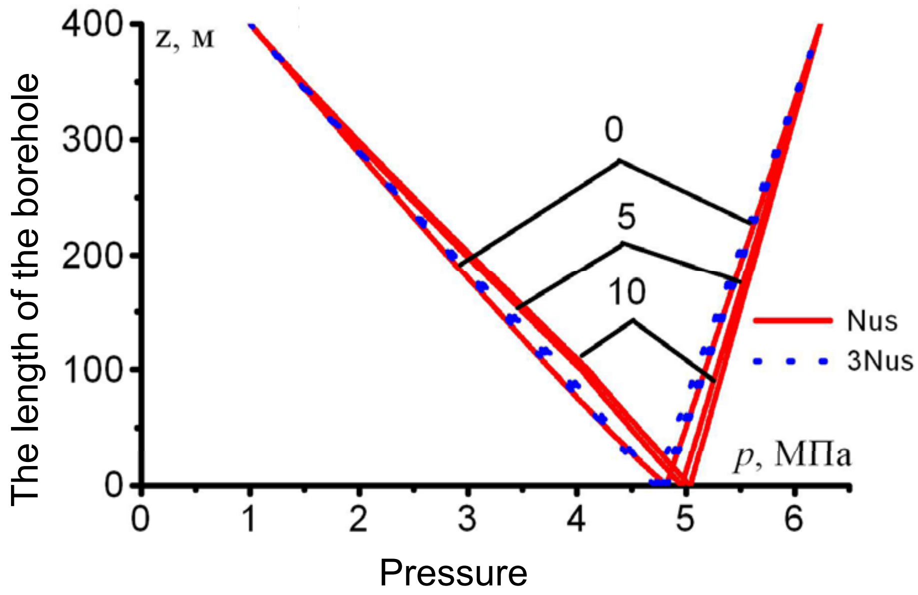
$$\frac{\partial a}{\partial t} = \frac{q^{(-)} - q^{(+)}}{\rho_h^0 l_h}, \qquad q^{(+)} = -\lambda_h \frac{\left(T_{h0} - T_a\right)\left(a - a_*\right)}{a\left(a_* - a - a_* \ln(a_*/a)\right)}$$

Evolution of hydrodynamic and temperature fields

$p_0^{(i)} = 6\text{МПа}, p_e = 1\text{МПа}, T_0^{(i)} = 300\text{К}$

$a_c^{(-)} = 0.05\,\text{м}, \ a_0 = 0.1\,\text{м}, \ z = 400\,\text{м}, H = 100\,\text{м}$

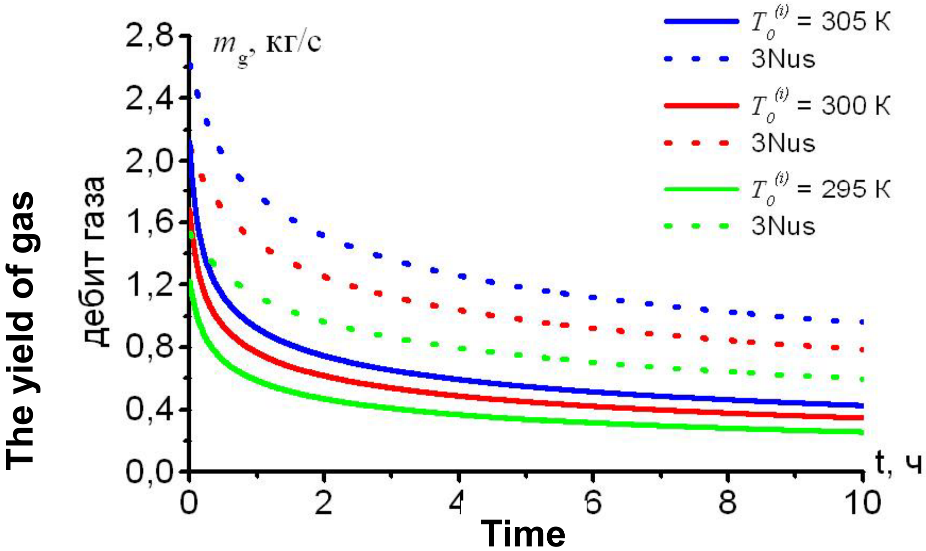




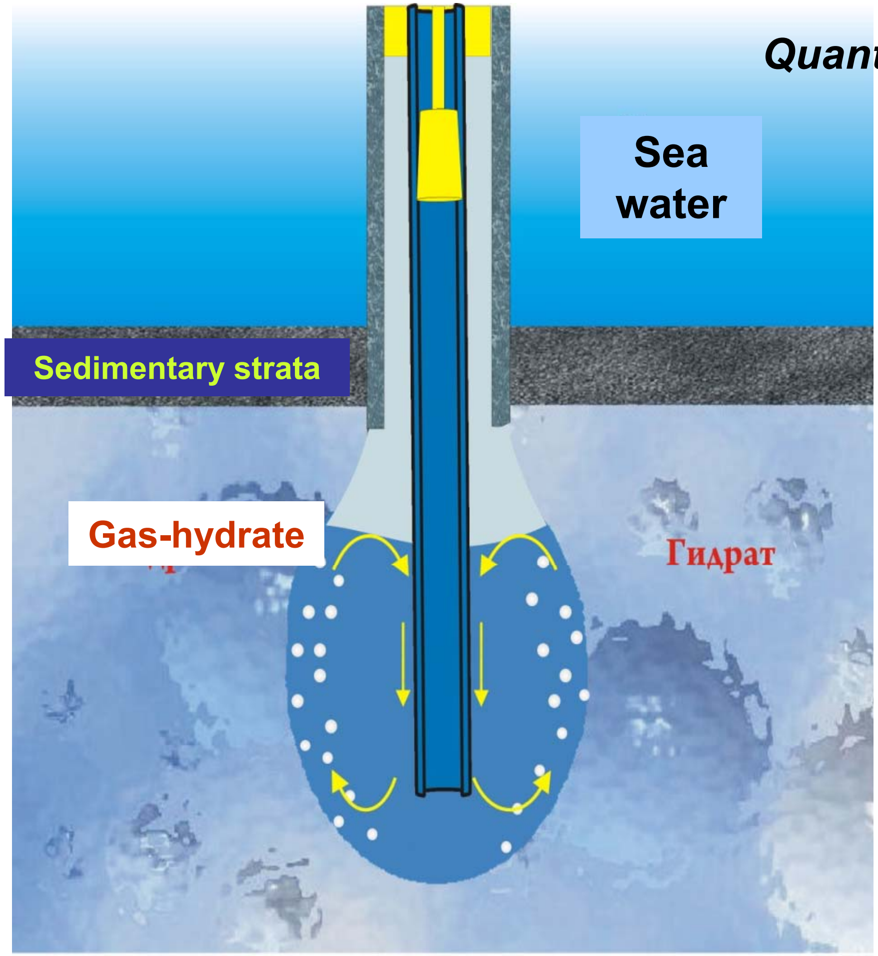
The numbers labels = the time, hour

Dynamics of well production $\left(p_0 = 6\text{МПа}, p_e = 1\text{МПа}, \ T_0 = 300\text{К} \right)$

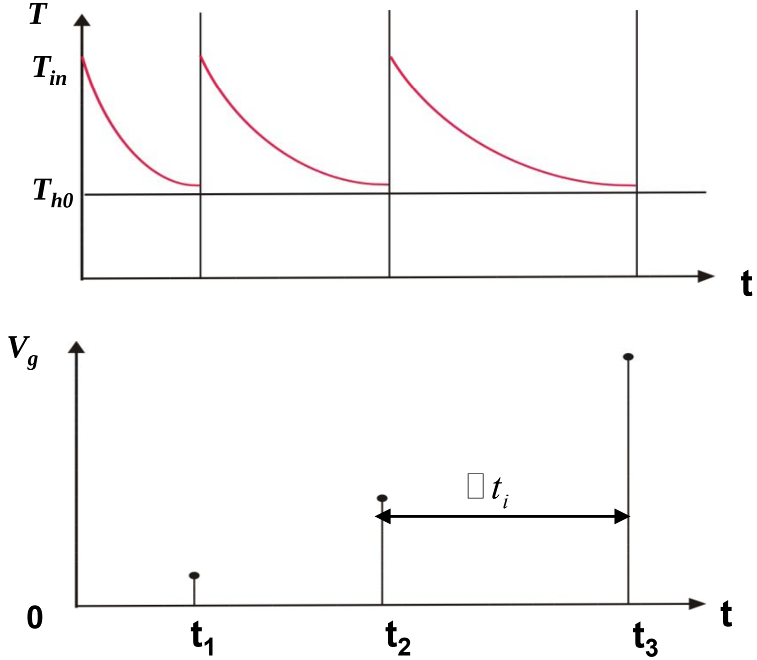
Depending on initial temperature of the heat carrier



Periodic Regime



Quantity of gas, washed out by the volume of water V_l



R ~ 1 m, H ~ 10 m, t = 5 - 6 hours

ΔT = 10 K:

$$\frac{V_g}{V_W} \approx 20$$

Energy Balance for Gas-Hydrate Production

Общие тепловые затраты на разложение газогидрата, находящегося в единице объема пористой среды

$$Q_{(-)} = \rho c V T + m \rho_h l_h$$

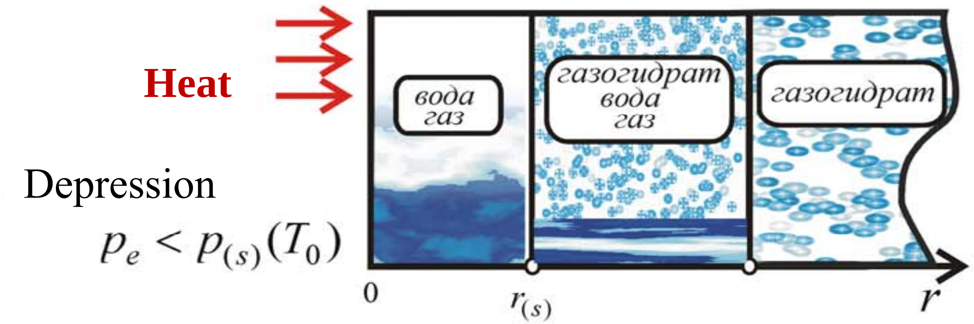
Methane Energy Resource

$$Q_{(+)} = m \rho_h G q$$

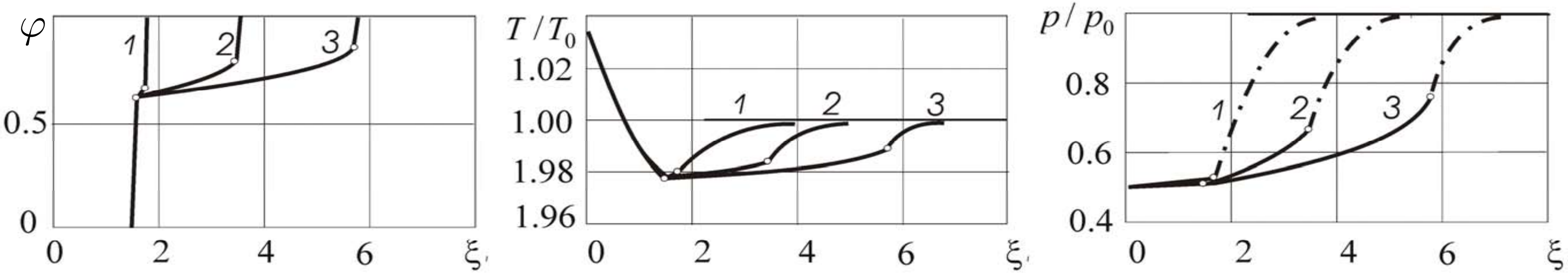
$$\Delta T = 10^{\circ}\,\mathrm{K}, \quad l_h = 5 \times 10^5\ \mathrm{J/kg}, \quad q = 4 \times 10^7\ \mathrm{J/kg}, \quad m = 0.1\,, \quad G = 0.1$$

EFFICIENCY $\dfrac{Q_{(+)}}{Q_{(-)}} \approx 10$

Phase Transition Wave in Porous Media Saturated by Gas-Hydrate

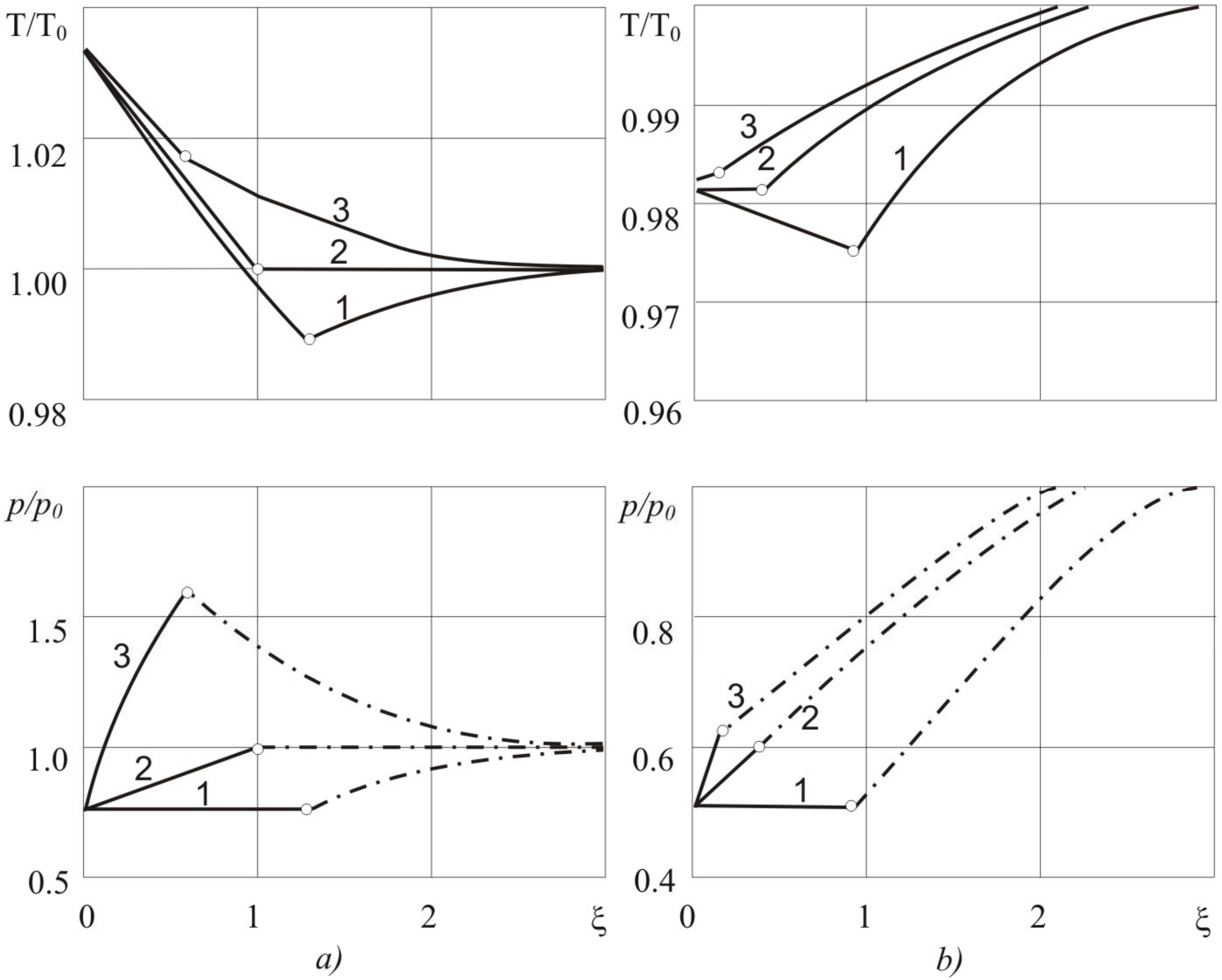


The solutions with a volume zone of Phase Transition Wave at different values of permeability



$$1 - k_0 = 10^{-14}\ \text{m}^2,\ 2 - k_0 = 4 \times 10^{-14}\ \text{m}^2, 3 - k_0 = 10^{-13}\ \text{m}^2$$

Saturation Shock in Low Permeability Porous Media with a Surface Jump

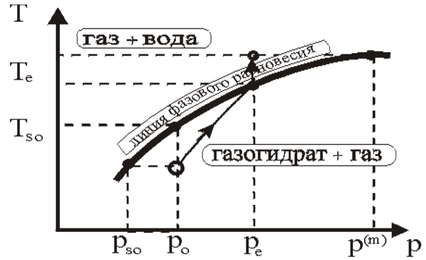


a) Disintegrating of the gas-hydrate in a porous medium at simultaneous heating and depression. The lines 1-3 correspond to permittivity of a skeleton $k_0 = 10^{-13}, 10^{-16}, 10^{-17}$ м^2;

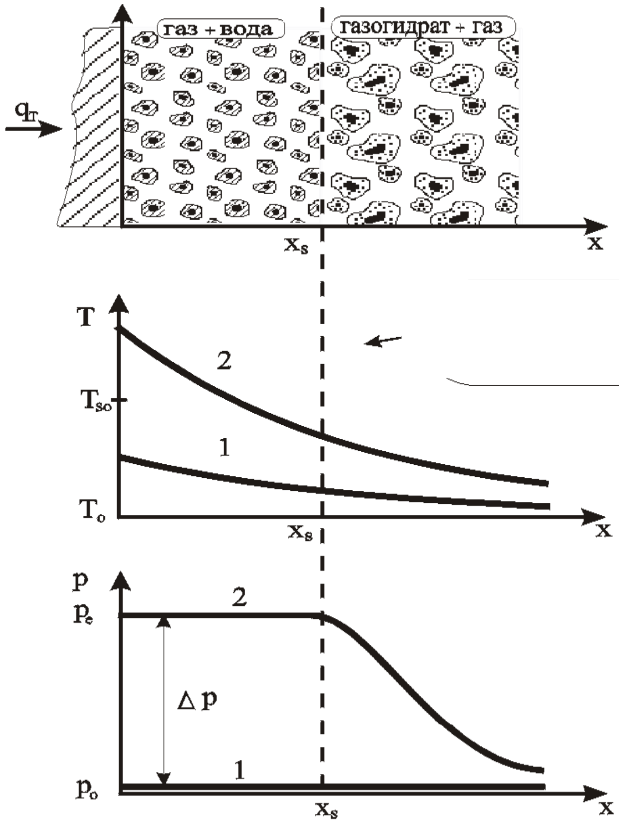
b) Disintegrating of the gas-hydrate at depression and reductuion of boundary temperature below initial.

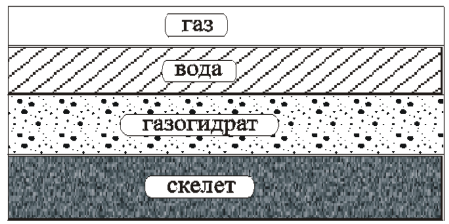
THERMAL GAS HYDRATE BOMB

Gas-hydrate of methan: density $\rho_h^0 \approx 900$ кг/м^3, The mass contents of gas ~10% (water 90%)

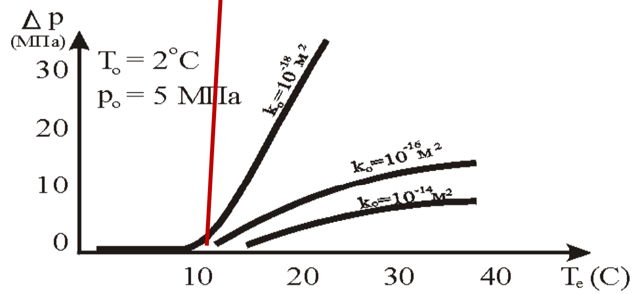


Thermal effect on gas-hydrate stratum through a weak permeable wall:





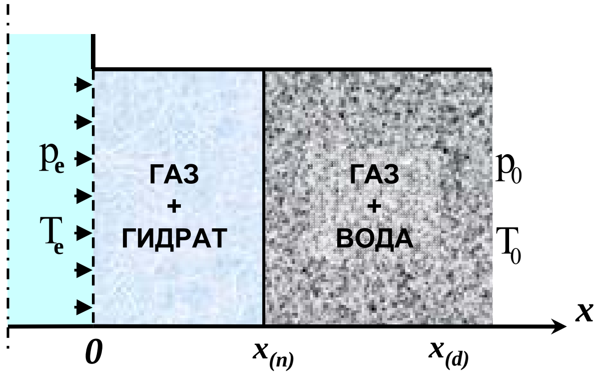
P = 80 Mpa (*k* = 0)



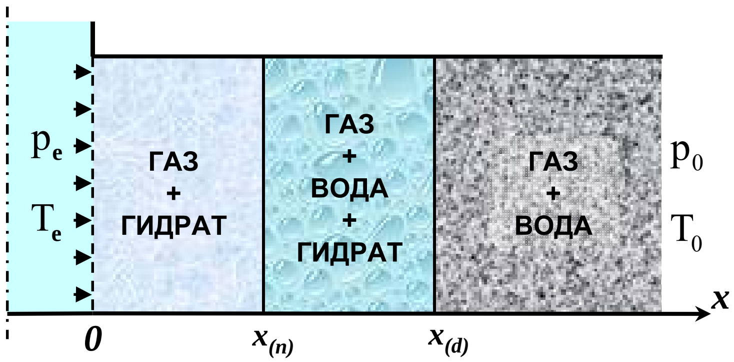
Maximal pressure, arising in the gas-hydrate stratum $p^{(m)} \approx 80$ МПа ($k_o = 0$)!

Two modes of hydrate formation at gas injection to the wet porous medium

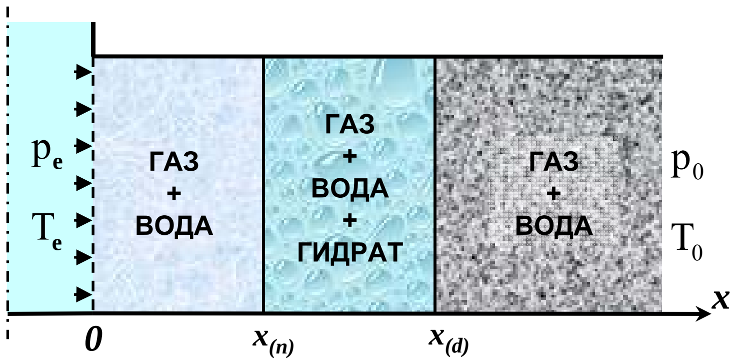
The hydrate is formed only at frontal boundary



The hydrate is formed in a volumetric zone

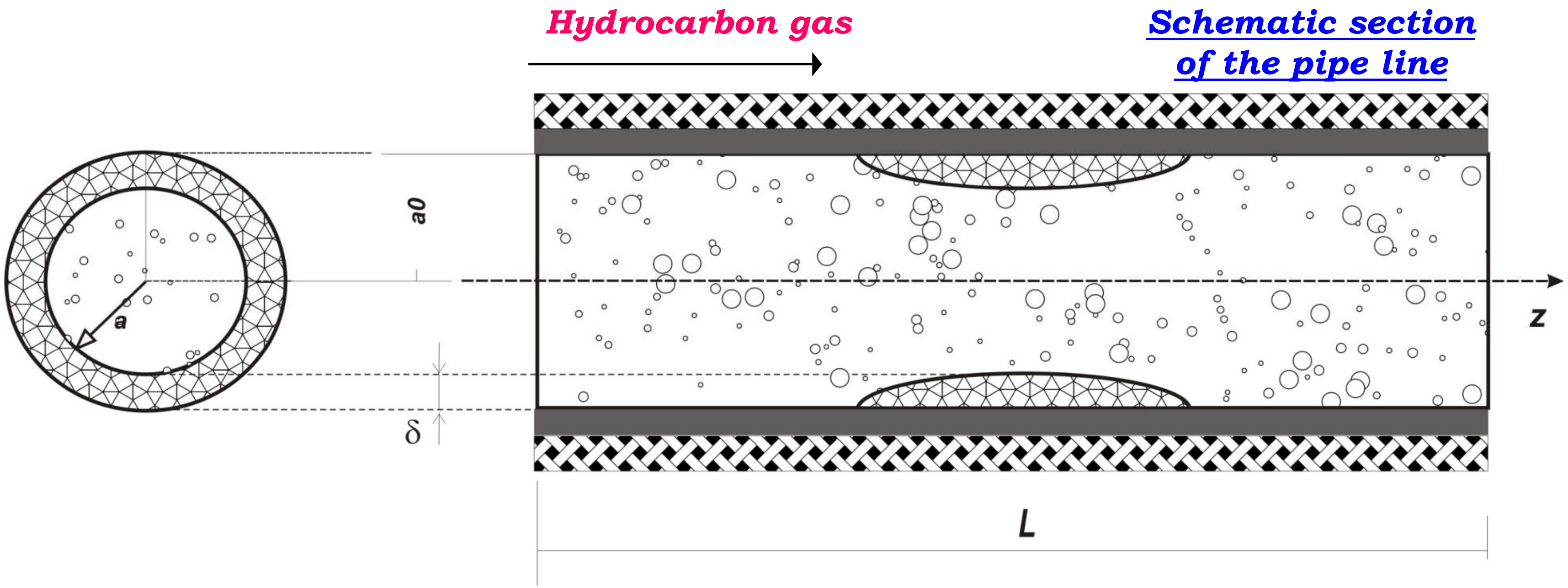


a) The near-field region is held by gas and hydrate



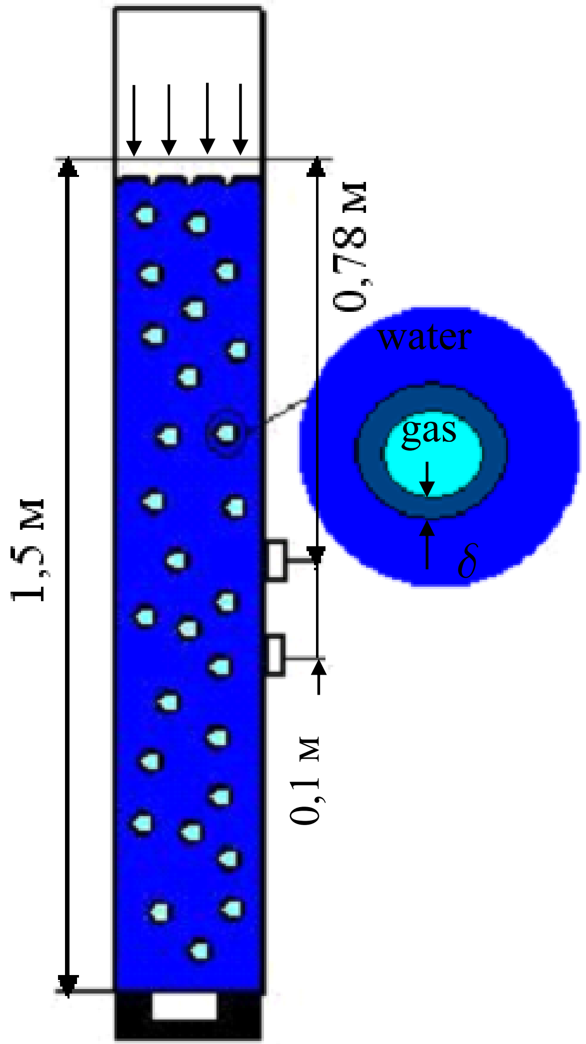
b) The near-field region is held by gas and water

Gas-Hydrates "SCLEROSIS" in pipe line



L – laid length, a_0 – inner radius, *a* – internal radius of a tube at presence of gas-hydrate layer, δ – Thickness of gas-hydrate layer.

Shock Wave Production of Gas-Hydrate



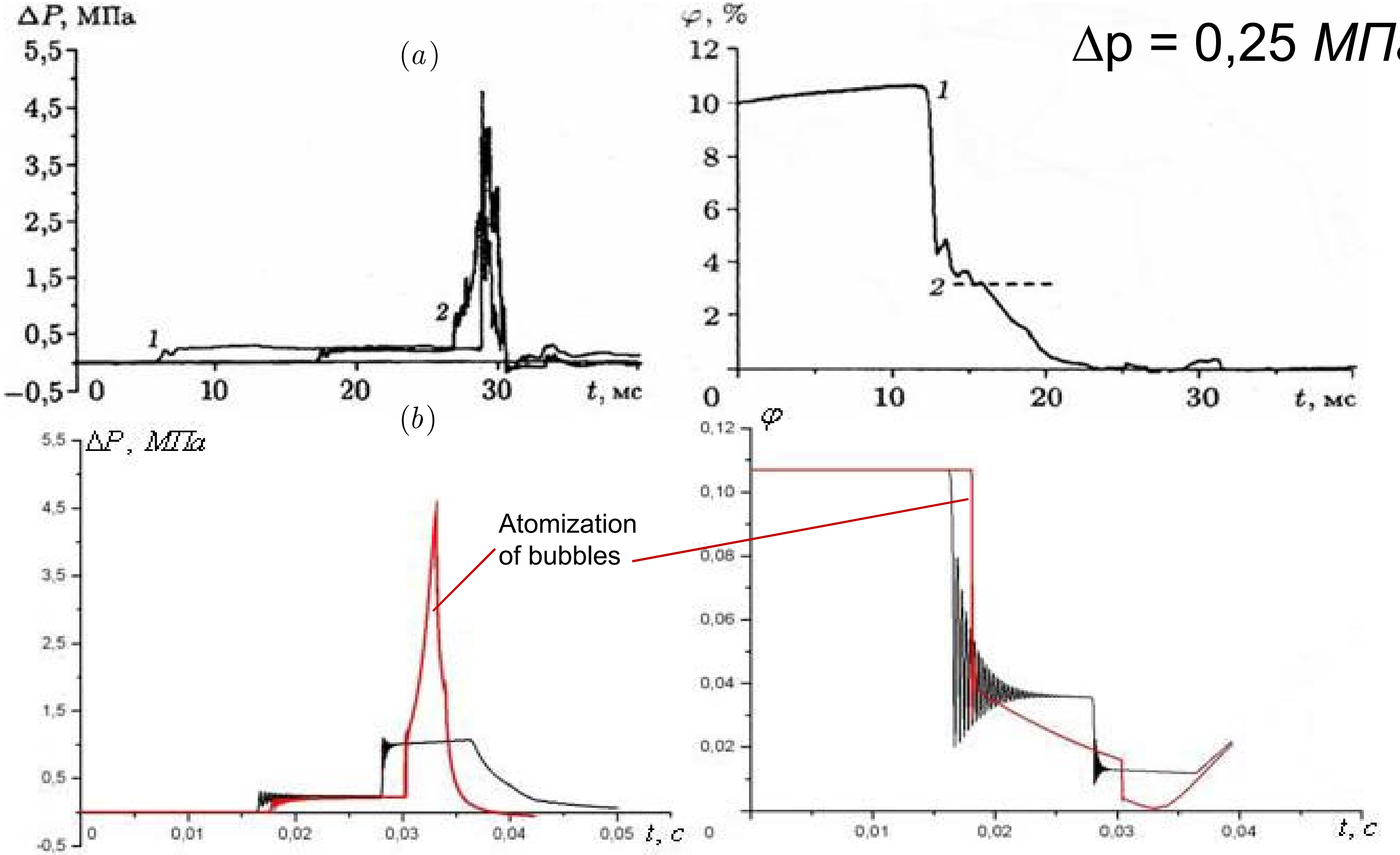
V.Y.Dontsov, V.Y. Nakoryakov, A.A. Chernov, 2007

Water with Freon-12 Gas Bubbles

Experimental (a) and computational (b) oscillograms of pressure and volumetric gas content

Metrics of gas liquid environment in section x = 1м from boundaries of a surface at a wave propagation of pressure in water with bubbles of Freon-12: $p_0 = 0,1 MПa; \quad a_0 = 2 \times 10^{-3} м; \quad \alpha_{g0} = 0,107; \quad T_0 = 274 K;$

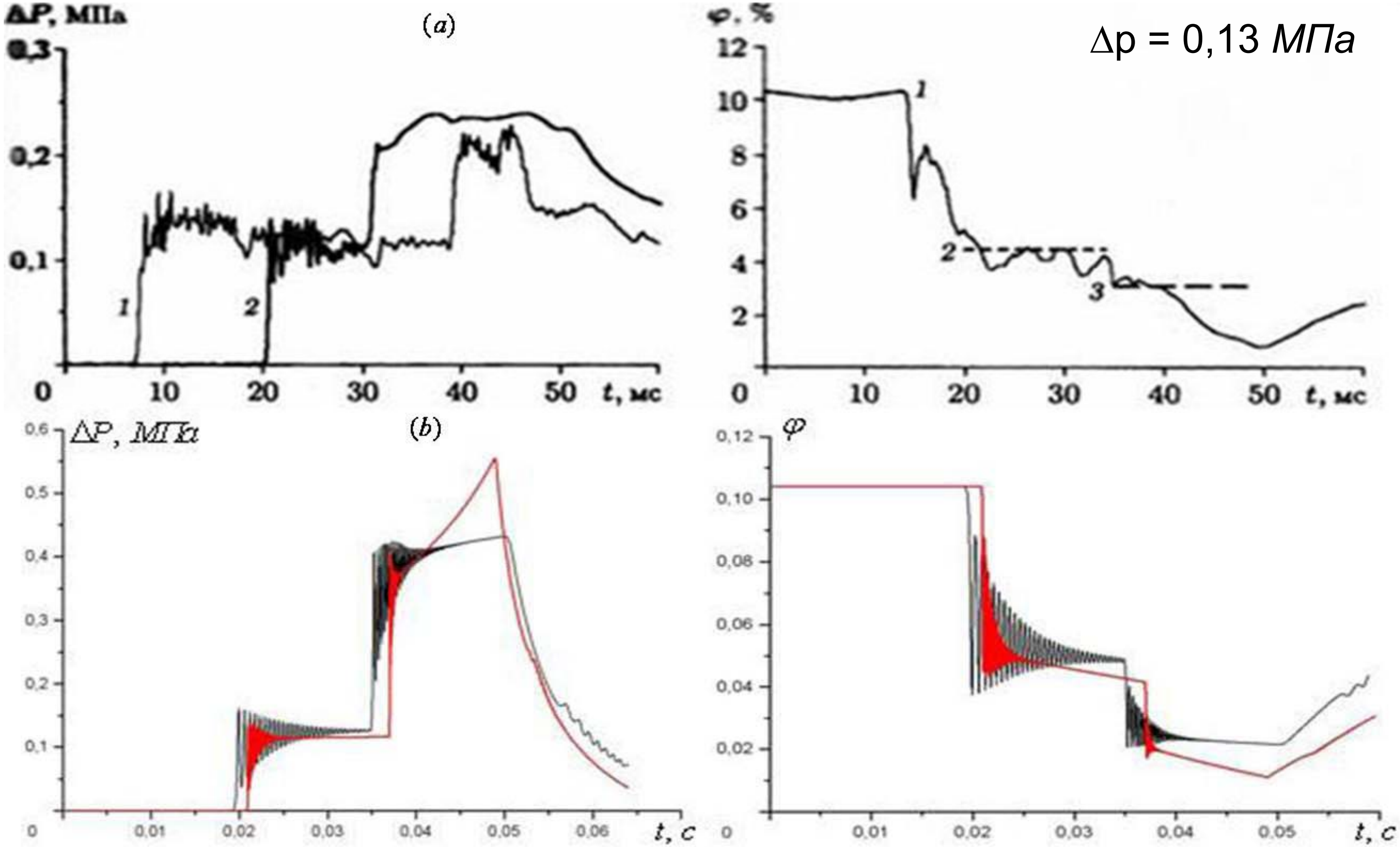
Wave amplitude: $\Delta p = 0,25$ *МПа*



The red and black computational oscillograms are obtained with the registration and without the registration of splitting of bubbles. The splitting takes place, if The current value of a Weber $\left(We = 2a\rho_g^0 \upsilon_{gl}^2 / \sigma\right)$ number at the moment of the maiden maximum contraction surpasses critical value $(We > 12)$. The number of pieces is determined from a condition, that the value of radius after splitting meets condition $(We \approx 12)$

Experimental (a) and computational (b) oscillograms of pressure and volumetric gas content

$$p_0 = 0{,}1 МПа; \quad a_0 = 2\times10^{-3} м; \quad \alpha_{g0} = 0{,}104; \quad T_0 = 274\,K;$$



The red and black computational oscillograms are obtained with the registration and without the registration of splitting of bubbles. The splitting takes place, if The current value of a Weber $\left(We = 2a\rho_g^0 v_{gl}^2/\sigma\right)$ number at the moment of the maiden maximum contraction surpasses critical value $(We > 12)$. The number of pieces is determined from a condition, that the value of radius after splitting meets condition $(We \approx 12)$

THANK YOU