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**THE EARLY TIME CONDENSATION IN THE NEAR WELL ZONE  
DURING NON-STATIONARY AND NON-ISOTHERMAL FLOW  
OF GAS CONDENSATE SYSEM**

**POCZĄTKOWA KONDENSACJA PODCZAS NIEIZOTERMICZNEGO  
I NIESTACJONARNEGO PRZEPŁYWU UKŁADU GAZOWO-KONDENSATOWEGO  
W POBLIŻU ODWIERTU**

This paper discusses one phase non-isothermal gas flow in porous media problems and investigation of Joule-Thomson effect influence on the gas flow temperature distribution in the near-well zone. Temperature effect in the near-well zone may be considered as an additional skin effect in the early-time analysis of transient gas well drawdown (or gas injection) tests with high constant rate at a wellhead. In case of condensate reservoirs the high temperature drop may cause the additional retrograde condensation of heavier components of hydrocarbon mixture. A system of four differential equations (motion, continuity, energy, state equation) has been solved in the near well zone. In the case of thin, non-isolated to the upper- and underburden reservoirs equation (5) must be modified for heat losses in vertical direction. In the present solution the vertical terms of energy transfer has been neglected. Term representing viscous dissipation in energy balance equation was regarded as negligible and was omitted. The paper includes considerations and solutions of mathematical model based upon Boltzman transformation of non-isothermal radial case gas flow in porous media. The system of four partial differential equations has been converted into two ordinary differential equations system and solved numerically using Runge-Kutta method. The properties of liquid and gas phase were evaluated using the Peng-Robinson equation of state during iteration procedure of solving main system of equation. The equilibrium model was solved by Quasi-Newton Successive Substitution (QNSS) and Dominant Eigenvalue Method (DEM) method. The new function (20) has been proposed, which describes the increase of liquid condensate in the reservoir. The function is computed numerically by using Richardson method based on VLE data and new ( $\beta_{ij}$ ) function in the near well zone.

If the value of liquid saturation is greater than critical the flow must be considered as the two-phase flow, so this analysis is non applicable. The presented model of correction of condensate saturation rate is more suitable than full equilibrium model in the near-well zone.

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of correction of condensate saturation rate is more suitable than full equilibrium model in the near-well zone. The condensate saturation profile in the near-well zone has been estimated and example of solution of changing liquid and gas composition versus time and reservoir radius. The graphs showing change of pressure, temperature, condensate saturation during the early stage of well exploitation has been presented.

**Key words:** Joule-Thomson effect, non-stationary and non-isothermal flow, temperature change, condensate outcrop, near-well zone

W artykule przedstawiono problem niestacjonarnej i nieizotermicznej filtracji gazu kondensatowego w bezpośrednim sąsiedztwie otworu. Głównym czynnikiem wpływającym na obniżenie się temperatury gazu jest efekt Joule'a-Thomsona. Rozwiązano układ równań różniczkowych cząstkowych dla gazu ziemnego w pobliżu odwiertu. Uwzględniono efekty nieliniowe w równaniu ruchu w ośrodku porowatym, równanie ciągłości, równanie stanu Penga-Robinsona i równanie bilansu energii. W rozwiązaniu pominięto straty ciepła spowodowane wymianą w kierunku pionowym powyżej i poniżej warstwy udostępnianej. Przedstawiono sposób transformacji układu równań różniczkowych cząstkowych na układ równań różniczkowych zwyczajnych z użyciem transformaty Boltzmanna. Rozwiązanie numeryczne układu równań różniczkowych zwyczajnych rozwiązano metodą Rungego-Kutty z odpowiednim uwzględnieniem warunków początkowych i brzegowych. Własności równowagowe fazy ciekłej i gazowej modelowano równocześnie w trakcie rozwiązywania układu równań zwyczajnych. Model równowagowy rozwiązano za pomocą dodatkowego układu równań nieliniowych metodą Quasi-Newton Successive Substitution (QNSS) i Dominant Eigenvalue Method (DEM) w oparciu o równanie Penga-Robinsona. Zaproponowano nową funkcję (20) opisującą przyrost nasycenia kondensatu w pobliżu odwiertu poniżej ciśnienia nasycenia przy nasyceniu cieczy mniejszym od krytycznego. Funkcja  $S(r, \tau)$  określona jest numerycznie metodą Richardsona na podstawie danych równowagowych kondensacji wstecznej (VLE) oraz funkcji ( $\beta_u$ ) uwzględniającej w sposób uproszczony efekt nierównowagowej kondensacji w pobliżu odwiertu. Rozwiązanie ograniczono do przypadku nasycenia fazą kondensatową w złożu poniżej krytycznego. Pokazano wyniki obliczeń w postaci przykładowych rozkładów zmienności składów faz ciekłej i gazowej oraz przebieg zmienności parametrów termodynamicznych gazu i kondensatu w funkcji czasu eksploatacji.

**Słowa kluczowe:** efekt Joule'a-Thomson, nieustalony i nieizotermiczny przepływ, zmiana temperatury, wykraplanie kondensatu, strefa przyotworowa

## Nomenclature

- $a, b$  — coefficients in EOS
- $\beta_u$  — correction factor for non-equilibrium condensation
- $c$  — compressibility
- $c_p$  — specific heat at constant pressure
- $F_b$  — turbulence coefficient
- $\phi$  — porosity coefficient
- $\psi$  — dissipation energy function
- $h$  — reservoir thickness
- $H$  — specific enthalpy
- $k$  — permeability coefficient
- $L, L'$  — mole fraction of liquid phase

$M_g$	— molecular mass of gas phase
$M_L$	— molecular mass of condensate
$\lambda$	— heat conductivity coefficient
$\mu$	— viscosity coefficient
$\mu_h$	— Joule-Thomson coefficient
$p$	— pressure
$q$	— volume output rate
$r$	— radial distance
$r_w$	— well radius
$R$	— universal gas constant
$\rho$	— density
$(\rho c)_o$	— specific heat of volume unit
$(\rho H)_o$	— enthalpy of porous medium volume unit
$s$	— specific density of natural gas
$S$	— condensate saturation of porous media
$t$	— time
$T$	— temperature
$\vec{u}$	— velocity vector
$\xi$	— dimensionless parameter
$v$	— volume
$Z_g$	— compressibility factor of gas phase
$Z_L$	— compressibility factor of condensate

## 1. Introduction

The investigation and simulation of gas flow through the reservoirs of natural gas is usually limited to the isothermal flows. In case of majority of natural gas reservoirs the changes of gas temperature have no significant influence on the production schedule. In some reservoirs the changes in gas temperature may have influence on gas condensate reservoirs (Siemek et al. 1987; Siemek, Nagy 1993). The detailed discussions and models of non-isothermal flow of gas with axial symmetry were shown by Siemek (1972).

## 2. Mathematical model of non-isothermal flow in porous media

The gas flow in porous media is described by the following differential equations: (i) equation of motion, (ii) equation of continuity, (iii) equation of state, (iv) energy conservation equation.

The Darcy law describes the velocity vector of gas flow:

$$\vec{u} = -\frac{k}{\mu} \cdot \text{grad}(p) \quad (1)$$

For the laminar flow — if the gas is flowing into near-well zone — one should take turbulence effects into account (Fizoozabadi, Katz 1979):

$$-\text{grad}p = \frac{\mu \cdot \vec{u}}{k_o} + F_b \cdot \vec{u} \cdot |\vec{u}| \quad (2)$$

The equation of continuity for one phase fluid in porous media has form:

$$\text{div}(\rho \cdot \vec{u}) + \phi \cdot \left( \frac{\partial \rho}{\partial t} \right) = 0 \quad (3)$$

The Peng-Robinson EOS (Peng, Robinson 1976) was used as equation of state:

$$p = \frac{RT \cdot \rho}{1 - b \cdot \rho} - \frac{a \cdot \rho^2}{(1 + 2\sqrt{2}b\rho)(1 - 2\sqrt{2}b\rho)} \quad (4)$$

The conservation energy law one may express by equation (Burger 1984):

$$\frac{\partial}{\partial t}(\rho H) + \text{div}(\rho H \vec{u}) = \text{div}(\lambda \cdot \text{grad}T) + \frac{\partial p}{\partial t} + \vec{u} \cdot \text{grad}p + \Psi \quad (5)$$

After neglecting last term in equation (5), which is representing dissipation of energy, and joining it with equation (2) one may write:

$$\text{div} \left( k \frac{\rho H}{\mu} \text{grad}p + \lambda \text{grad}T \right) + \frac{\partial p}{\partial t} - \frac{k}{\mu} (\text{grad}p)^2 = \frac{\partial(\rho H)_o}{\partial t} \quad (6)$$

where change of porous medium enthalpy and porous rock enthalpy of unit volume in the time is expressed as:

$$\frac{\partial(\rho H)_o}{\partial t} = \phi \rho \cdot c_p \left( \frac{\partial T}{\partial t} - \mu_h \frac{\partial p}{\partial T} \right) + (1 - \phi)(\rho c)_r \frac{\partial T}{\partial t} \quad (7)$$

Equations (2), (3), (4), (5) are complete system for solution of the non isothermal one phase gas flow in reservoir. The method of gas flow solution specially used in non steady state of reservoir is conversion of (2, 3, 4, 5) equation set to dimensionless set of ordinary coupled system based on use of the Boltzmann transformation. Let's assume that reservoir is homogeneous of uniform thickness and of infinite extend (non steady state). Using  $\pi$ -Buckingham theorem and introducing dimensionless variables:

$$p = \frac{p}{p_i}, \quad T = \frac{T}{T_i}, \quad \xi = r \sqrt{\frac{\phi \cdot \mu}{k \cdot p_i \cdot t}} \quad (8)$$

and neglecting the dissipation term in eq. (5) one may write equations system (2, 3, 4, 5) in following form (9, 10, 11):

$$\frac{k \cdot \rho \cdot H \cdot p_i}{\lambda \cdot \mu \cdot T_i} \left\{ \left( \frac{\partial \ln H}{\partial p} - \frac{p_i}{\rho H} \right) \left( \frac{d\bar{p}}{d\xi} \right)^2 + \frac{\partial \ln H}{\partial p} \left( \frac{d\bar{p}}{d\xi} \right) \left( \frac{d\bar{T}}{d\xi} \right) + \right. \quad (9)$$

$$\left. \frac{\xi}{2} \left[ \left( \frac{(\rho c)_r}{\rho H} T_i - \frac{\partial \ln p}{\partial \bar{T}} \right) \left( \frac{d\bar{T}}{d\xi} \right) - \left( \frac{\phi \rho c_p \mu_h + 1}{\phi} \frac{p_i}{\rho H} + \frac{\partial \ln \rho}{\partial \bar{T}} \right) \left( \frac{d\bar{p}}{d\xi} \right) \right] \right\} +$$

$$+ \frac{\left( \frac{d\bar{T}}{d\xi} \right)}{\xi} + \left( \frac{d^2 T}{d\xi^2} \right) = 0$$

$$\left( \frac{d\bar{T}}{d\xi} \right) \frac{1}{\xi} + \left( \frac{d^2 T}{d\xi^2} \right) + \frac{\partial \ln \rho / \mu}{\partial \bar{p}} \left( \frac{d\bar{p}}{d\xi} \right)^2 + \frac{\partial \ln \rho / \mu}{\partial \bar{T}} \left( \frac{d\bar{T}}{d\xi} \right) \left( \frac{d\bar{p}}{d\xi} \right) + \quad (10)$$

$$+ \frac{\xi}{2} \left[ \left( \frac{\partial \ln \rho}{\partial \bar{p}} \right) \left( \frac{d\bar{p}}{d\xi} \right) + \left( \frac{\partial \ln \rho}{\partial \bar{T}} \right) \left( \frac{d\bar{T}}{d\xi} \right) \right] = 0$$

$$\rho = \rho(p, T) \quad (11)$$

For this system the following boundary and initial conditions are chosen:

$$t = 0 \quad r > r_w \quad p = p_i \quad T = T_i \quad \xi = \infty, \quad \bar{p} = 1, \quad \bar{T} = 1 \quad (12)$$

$$t > 0 \quad r = \infty, \quad p = p_i \quad T = T_i \quad \xi = \infty, \quad \bar{p} = 1, \quad \bar{T} = 1 \quad (13)$$

### 3. Results

The thermodynamic parameters like heat capacity, Joule-Thomson coefficient, viscosity, compressibility coefficient, heat conduction coefficient, enthalpy were assumed to be constant. Term representing viscous dissipation in energy balance equation was regarded as negligible and was omitted.

Following data was chosen for calculation:

$$(\rho c)_r = 2.82 \cdot 10^6 \text{ J/m}^3/\text{K}, \quad \lambda = 1.73 \text{ W/m/K},$$

$$s = 0.6, M = 17.4 \text{ kg/kmol}, \phi = 0.02,$$

$$\mu_h = 0.4 \text{ K/bar}, c_p = 3.1 \text{ kJ/kg/K},$$

$$p = 10 \text{ MPa}, T = 300 \text{ K}, \mu = 1.98 \cdot 10^{-5} \text{ Pa}\cdot\text{s},$$

$$k = 24.1 \cdot 10^{-15} \text{ m}^2, m^o(r_w) = 8165 \text{ kg/h},$$

The Fig. 1 to 6 show solution of set of (9, 10, 11) equations in the near-well zone as a function of time and radial distance. From this figures one may see that the temperature gradient is especially great in the well vicinity (up to 8.2 K/MPa, 8.6 K/m — for this example). The filtration velocity versus radius for the time  $t = 120$  days is shown in the Fig. 7. Knowing the  $T(r, t)$  and  $p(r, t)$  functions and performing the phase envelope (Fig. 8) and the flash calculations for vapor-liquid phases distributions ( $L(r, t), V(r, t)$ ) it is possible to determine rate of condensate saturation in the near-well zone. In the Fig. 9 is presented the  $C_{3+}$  hydrocarbon content of outcropped condensate versus reservoir radius for the series of production time.

The compositions of equilibrium phases were computed using set of equations:

$$L \cdot x_i + V \cdot y_i - z_i = 0 \quad (i=1, \dots, n) \quad (14)$$

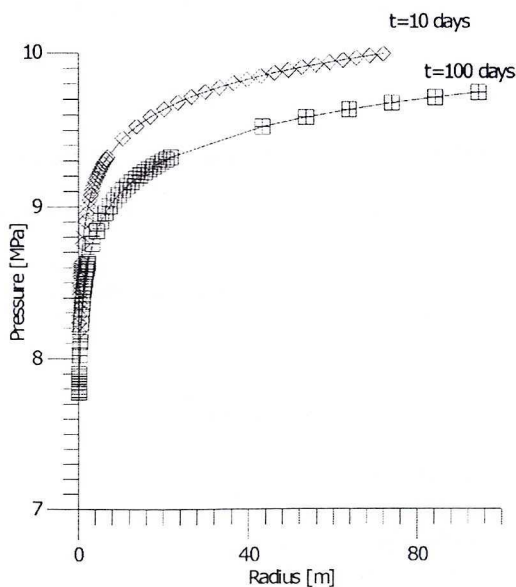


Fig. 1. Distribution of drawdown pressure versus reservoir radius after 10 and 100 days.

Rys. 1. Rozkład ciśnienia w funkcji promienia złoza po czasie 10 i 100 dni eksploatacji

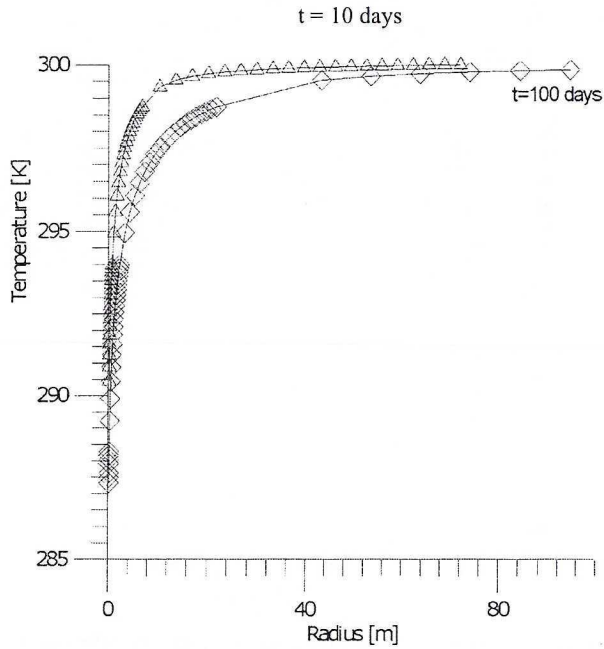


Fig. 2. Distribution of drawdown temperature versus reservoir radius after 10 and 100 days  
 Rys. 2. Rozkład temperatury w funkcji promienia złoza po czasie 10 i 100 dni eksploatacji

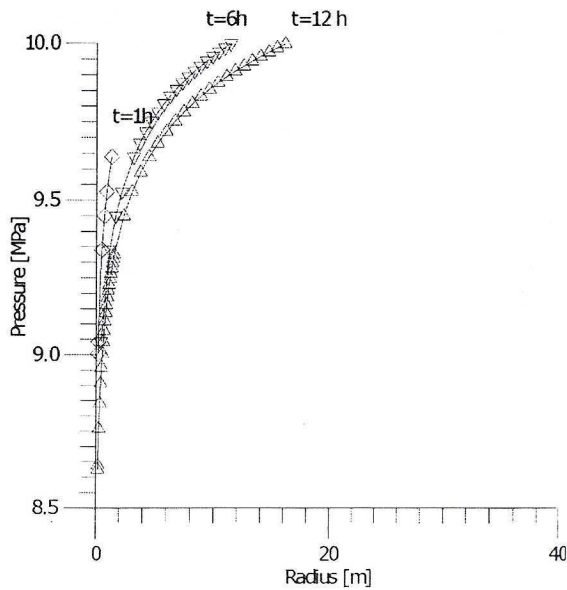


Fig. 3. Distribution of drawdown pressure versus reservoir radius after 1, 6 and 12 hours  
 Rys. 3. Rozkład ciśnienia w funkcji promienia złoza po czasie 1, 6, 12 godzin eksploatacji

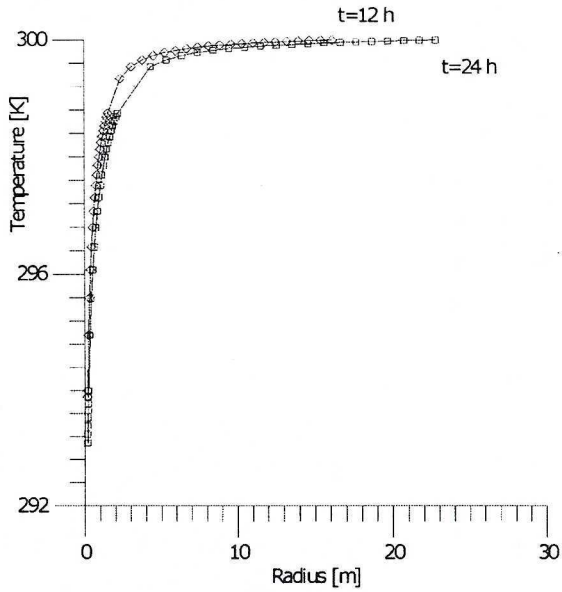


Fig. 4. Distribution of drawdown temperature versus reservoir radius after 12 and 24 hours.

Rys. 4. Rozkład temperatury w funkcji promienia złoża po czasie 12 i 24 godzin eksploatacji

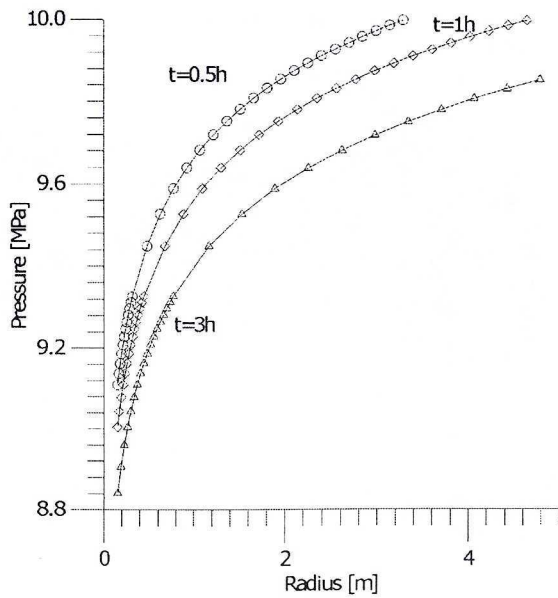


Fig. 5. Distribution of drawdown pressure versus reservoir radius after 0.5, 1, 3 hours.

Rys. 5. Rozkład ciśnienia w funkcji promienia złoża po czasie 0,5, 1, 3 godzin eksploatacji



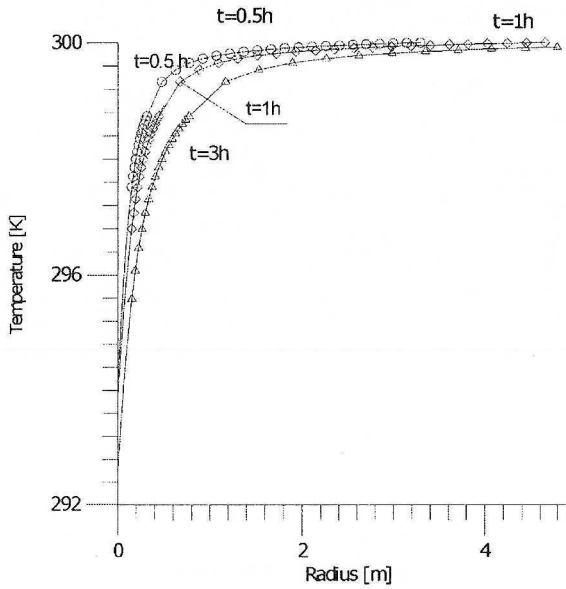


Fig. 6. Distribution of drawdown temperature versus reservoir radius after 0.5, 1, 3 hours

Rys. 6. Rozkład temperatury w funkcji promienia złoza po czasie 0,5, 1, 3 godzin eksploatacji

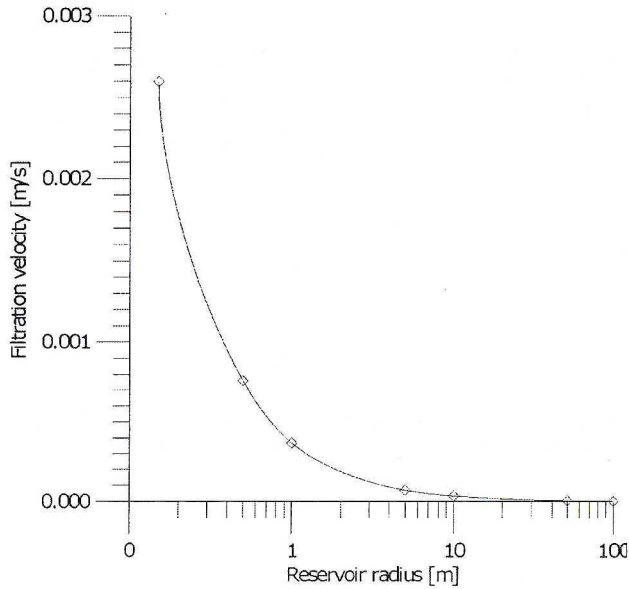


Fig. 7. Filtration velocity versus reservoir radius in the time 120 days after drawdown start

Rys. 7. Rozkład prędkości filtracji w funkcji promienia złoza po 120 dniach eksploatacji

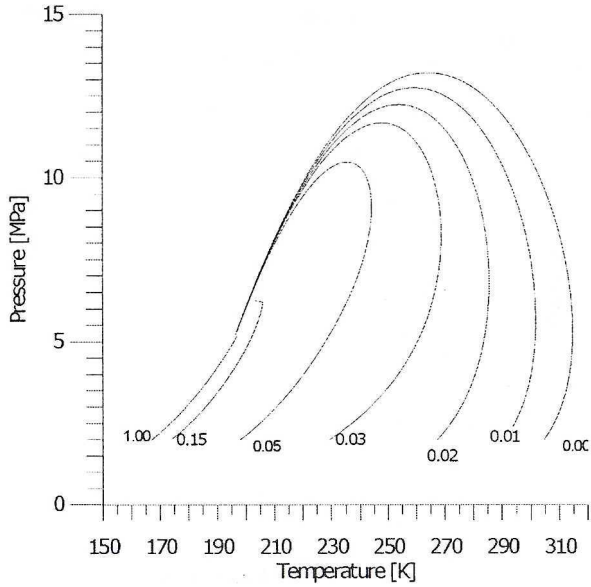


Fig. 8. Phase envelope of natural gas mixture ( $C_1 = 0.95$ ,  $C_2 = 0.2$ ,  $C_3 = 0.1$ ,  $C_6 = 0.2$ ) calculated using Peng-Robinson EOS (isolines with constant liquid mole fraction)

Rys. 8. Krzywa kondensacji i krzywa wrzenia układu gazowo-kondensatowego ( $C_1 = 0.95$ ,  $C_2 = 0.2$ ,  $C_3 = 0.1$ ,  $C_6 = 0.2$ ) obliczona równaniem stanu Peng-Robinson (izolinie oznaczają udział fazy ciekłej)

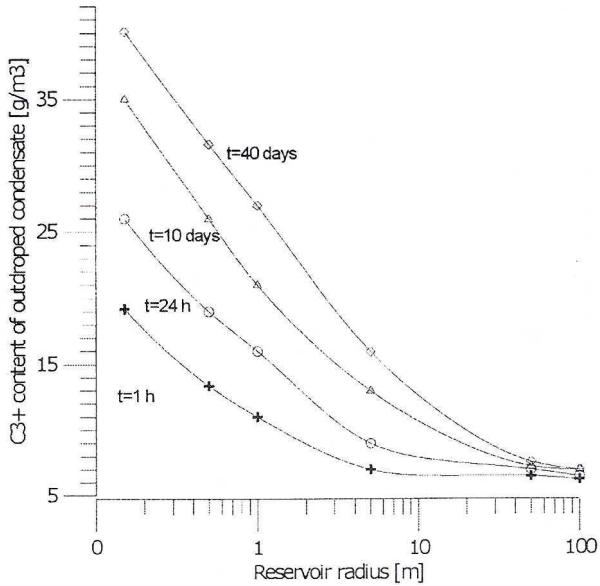


Fig. 9.  $C_{3+}$  content of outcropped condensate versus reservoir radius

Rys. 9. Nasylenie węglowodorów ciekłych ( $C_{3+}$ ) w funkcji promienia złoża

where liquid mole fractions  $L$  and vapor mole fractions were calculated after solution of equation:

$$\sum_{i=1}^n x_i - \sum_{i=1}^n y_i = 0 \quad (15)$$

and the equilibrium constant is defined as,

$$K_i = \frac{y_i}{x_i} \quad (16)$$

or using fugacity coefficients

$$K_i = \frac{\phi_i^L}{\phi_i^V} \quad (17)$$

$$\phi_i^L = \frac{f_i^L}{x_i P}, \quad \phi_i^V = \frac{f_i^V}{y_i P} \quad (i = 1, \dots, n) \quad (18)$$

The fugacity coefficients are calculated using Peng-Robinson equation of state (Peng, Robinson 1976). For the convergence of equation scheme the model QNSS(C) or DEM (Nagy 1991).

The function of volume output rate with the reservoir radius and the time is presented in Fig.10. To estimate the percent of liquid molar fraction really outcropped from gas during turbulent flow following model has been proposed.

Let's assume that  $\Delta\tau = \Delta r/u$  is the characteristic time needed for full condensation of  $L(r,\tau)$  mole fraction of gas flowing through the element  $dv'$  having the width  $\Delta r'$  in time  $\Delta\tau' = r'/u$ . For one mole of gas flowing through the  $dv'$  element the volume which changed into liquid state is equal to (Siemek at al. 1978):

$$\frac{\Delta r'}{u'} \frac{u}{\Delta r} L'(r', \tau)$$

Finally, the correction term representing the non-equilibrium condensation has form:

$$\beta_u = \begin{cases} \frac{\Delta r'}{u'} \frac{u}{\Delta r} & \text{for } \frac{\Delta r'}{u'} < \frac{\Delta r}{u} \\ 1 & \text{for } \frac{\Delta r'}{u'} \geq \frac{\Delta r}{u} \end{cases} \quad (19)$$

As a criterion of full equilibrium condensation of liquid, the reference velocity  $u$  is assumed velocity at radius  $r' = 10$  m for time  $\tau = 10$  day since production start. The chose of reference velocity may be different depending pressure and temperature gradient. The assumed value  $u$  was chosen after performing of sensitivity analyze.

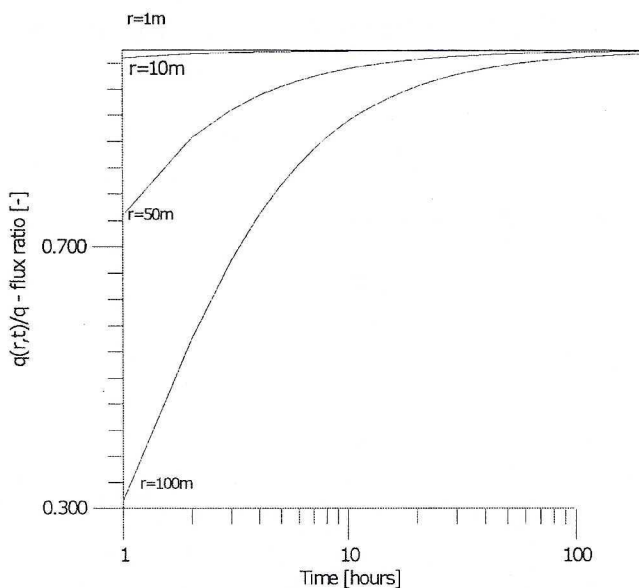


Fig. 10. Ratio  $q(r,t)/q$  versus time for reservoir radius  $r = 1\text{ m}$ ,  $r = 10\text{ m}$ ,  $r = 50\text{ m}$ ,  $r = 100\text{ m}$   
 Rys. 10. Stosunek prędkości filtracji  $q(r,t)/q$  w funkcji czasu dla promienia złożowego  $r = 1\text{ m}$ ,  
 $r = 10\text{ m}$ ,  $r = 50\text{ m}$ ,  $r = 100\text{ m}$

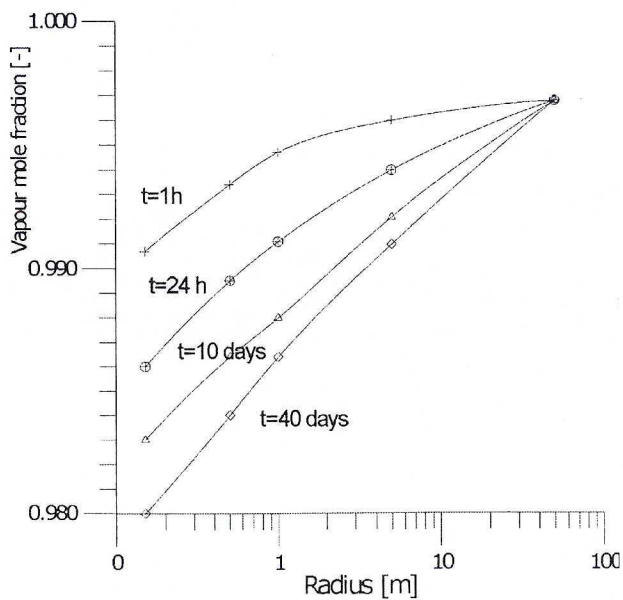


Fig. 11. Vapour fraction of mixture versus reservoir radius (time = 1 h, 24 h, 10 days, 40 days)  
 Rys. 11. Udział fazy gazowej w funkcji promienia złożowego (po czasie 1 h, 24 h, 10 dni, 40 dni)

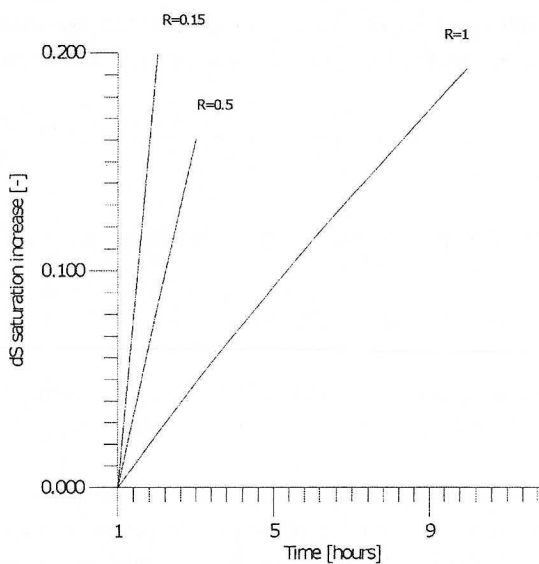


Fig. 12a. Condensate saturation increase versus time for selected reservoir radius for full-equilibrium model

Rys. 12a. Przyrost nasycenia kondensatem w strefie przyodwiertowej w funkcji czasu eksploatacji dla promienia  $r = 0,15$  m,  $r = 0,5$  m,  $r = 1$  m dla modelu pełnej równowagi termodynamicznej

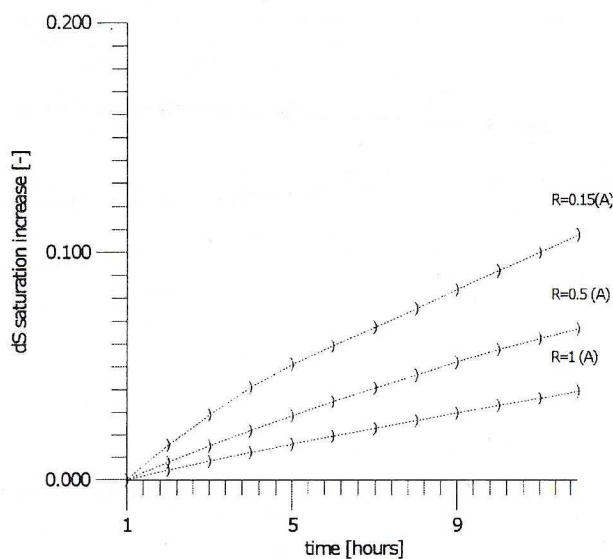


Fig. 12b. Condensate saturation increase versus time for selected reservoir radius for proposed model (A) using equation (20)

Rys. 12b. Przyrost nasycenia kondensatem w strefie przyodwiertowej w funkcji czasu eksploatacji dla promienia  $r = 0,15$  m,  $r = 0,5$  m,  $r = 1$  m dla proponowanego modelu (A) według równania (20)

The equation which describe the saturation of condensate (defined as a percent of liquid volume condensed in the free porous volume) has the form:

$$S(r, \tau) = S(r, \tau_0) + \int_{\tau_0}^{\tau} \beta_u \frac{\partial}{\partial p} \left[ \frac{M_g}{M_L} \frac{Z_L}{Z_g} L'(r', \tau) \right] \frac{Dp}{D\tau} d\tau \quad (20)$$

where the first derivative is computed using numerical methods and  $\frac{Dp}{D\tau}$  substantial

derivative of pressure versus time and term  $\frac{\partial}{\partial p} \left[ \frac{M_g}{M_L} \frac{Z_L}{Z_g} L'(r', \tau) \right]$  is representing the

change of condensate volume in the element volume  $dv$  during equilibrium condensation as a pressure function. The integral in the equation (20) is calculated using numerical methods.

The vapor mole fraction  $V(r, \tau)$  as a function of time and radius has been presented in Fig. 11. The calculation was made for reference filtration velocity value taken in the reservoir radius  $r = 0.5$  m. The final results of gas condensate saturation distribution (equilibrium and proposed method (marked as "a") using eq.(20)) is shown in Fig. 12. The change of liquid composition of outcropped condensate is shown in Fig. 13. The solution of VLE calculation for selected time points is presented in Table 1. In The vaporization constant  $K$  and liquid phase fraction of stream are shown in the

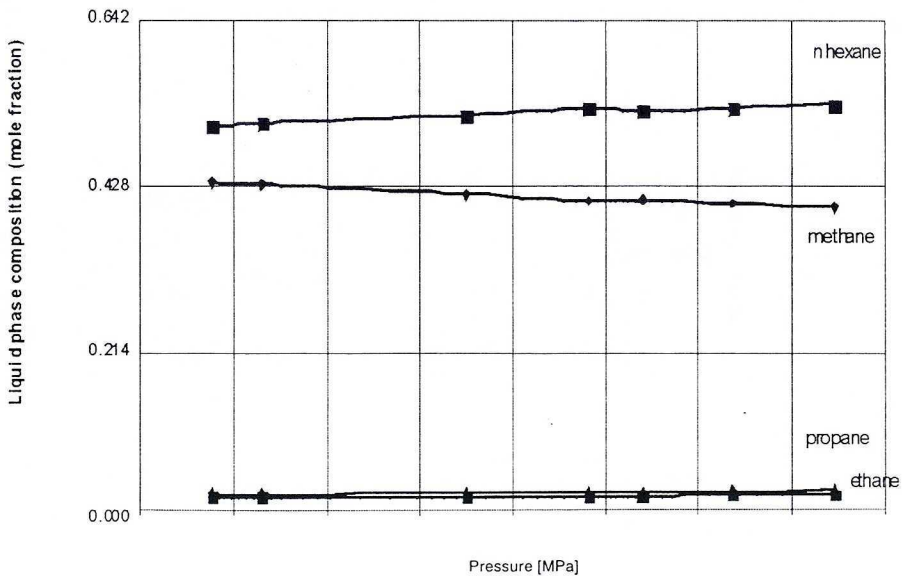


Fig. 13. Change of liquid phase composition of gas-condensate versus pressure at 0.5 m reservoir radius

Rys. 13. Zmiana koncentracji wybranych składników układu gazowo-kondensatowego dla promienia złożowego  $r = 0,5$  m

TABLE I

Equilibrium of vapor-liquid equilibrium for several time points in function of equivalent pressure and temperature at reservoir radius ( $r = 0.5$  m)

TABLICA I

Równowagowy skład fazy ciekłej i gazowej w funkcji czasu dla wartości ciśnienia i temperatury odpowiadających promieniowi złożowemu ( $r = 0,5$ m)

a)  $t = 1.5$  h

	$K[i]$	$z[i]$	$x[i]$	$y[i]$
Methane	2.1920	0.9500	0.4348	0.9531
Ethane	0.7155	0.0200	0.0279	0.0200
Propane	0.3215	0.0100	0.0307	0.0099
n-hexane	0.0337	0.0200	0.5066	0.0170

$p = 9.45$  [MPa];  $T = 299.330$  [K];  $V = 0.9940$ ;  $ZV = 0.7938$ ;  $ZL = 0.3659$ ;  $C_{3+} = 12.12$ [g/Sm<sup>3</sup>]

b)  $t = 1.5$  day

	$K[i]$	$z[i]$	$x[i]$	$y[i]$
Methane	2.2115	0.9500	0.4311	0.9535
Ethane	0.7155	0.0200	0.0279	0.0199
Propane	0.3194	0.0100	0.0309	0.0099
n-hexane	0.0328	0.0200	0.5101	0.0167

$p = 9.34$  [MPa];  $T = 299.100$  [K];  $V = 0.9934$ ;  $ZV = 0.7953$ ;  $ZL = 0.3627$ ;  $C_{3+} = 13.37$ [g/Sm<sup>3</sup>]

c)  $t = 10$  days

	$K[i]$	$z[i]$	$x[i]$	$y[i]$
Methane	2.2777	0.9500	0.4195	0.9554
Ethane	0.7054	0.0200	0.0282	0.0199
Propane	0.3050	0.0100	0.0320	0.0098
n-hexane	0.0286	0.0200	0.5203	0.0149

$p = 8.90$  [MPa];  $T = 296.460$  [K];  $V = 0.9899$ ;  $ZV = 0.7982$ ;  $ZL = 0.3495$ ;  $C_{3+} = 20.89$ [g/Sm<sup>3</sup>]

d)  $t = 40$  days

	$K[i]$	$z[i]$	$x[i]$	$y[i]$
Methane	2.3307	0.9500	0.4102	0.9561
Ethane	0.7069	0.0200	0.0282	0.0199
Propane	0.3009	0.0100	0.0324	0.0097
n-hexane	0.0270	0.0200	0.5292	0.0143

$p = 8.64$  [MPa];  $T = 296.000$  [K];  $V = 0.9889$ ;  $ZV = 0.8022$ ;  $ZL = 0.3418$ ;  $C_{3+} = 23.35$ [g/Sm<sup>3</sup>]

e)  $t = 4$  months

	$K[i]$	$z[i]$	$x[i]$	$y[i]$
Methane	2.3268	0.9500	0.4115	0.9574
Ethane	0.6897	0.0200	0.0288	0.0199
Propane	0.2890	0.0100	0.0335	0.0097
n-hexane	0.0248	0.0200	0.5262	0.0130

$p = 8.52$  [MPa];  $T = 293.090$  [K];  $V = 0.9864$ ;  $ZV = 0.7989$ ;  $ZL = 0.3379$ ;  $C_{3+} = 28.37$  [g/Sm<sup>3</sup>]

f)  $t = 1$  year

	$K[i]$	$z[i]$	$x[i]$	$y[i]$
Methane	2.3557	0.9500	0.4068	0.9583
Ethane	0.6830	0.0200	0.0291	0.0199
Propane	0.2816	0.0100	0.0342	0.0096
n-hexane	0.0231	0.0200	0.5299	0.0122

$p = 8.325$  [MPa];  $T = 291.580$  [K];  $V = 0.9850$ ;  $ZV = 0.7998$ ;  $ZL = 0.3319$ ;  $C_{3+} = 31.64$  [g/Sm<sup>3</sup>]

g)  $t = 2$  years

	$K[i]$	$z[i]$	$x[i]$	$y[i]$
Methane	2.3881	0.9500	0.4017	0.9592
Ethane	0.6755	0.0200	0.0294	0.0198
Propane	0.2736	0.0100	0.0350	0.0096
n-hexane	0.0213	0.0200	0.5340	0.0114

$p = 8.11$  [bar];  $T = 289.900$  [K];  $V = 0.9835$ ;  $ZV = 0.8008$ ;  $ZL = 0.3252$ ;  $C_{3+} = 35.07$  [g/Sm<sup>3</sup>]

TABLE 2

Changing of vaporization constant  $K$  for reservoir radius  $r = 0.5$  m for time: 1.5 h, 1.5 day, 10 days, 40 days, 4 months, 1 year, 2 years

TABLICA 2

Zmiana stałej równowagi fazowej  $K$  dla promienia złożowego  $r = 0,5$  m dla czasu 1,5 h, 1,5 dnia, 10 dni, 40 dni, 4 miesiące, 1 rok, 2 lata

T[K]	299.33	299.10	296.46	296.00	293.09	291.58	289.90
P[MPa]	9.45	9.34	8.90	8.64	8.52	8.325	8.11
Methane	2.1920	2.2115	2.2777	2.3307	2.3268	2.3557	2.3881
Ethane	0.7155	0.7155	0.7054	0.7069	0.6897	0.6830	0.6755
Propane	0.3215	0.3194	0.3050	0.3009	0.2890	0.2816	0.2736
n-hexane	0.0337	0.0328	0.0286	0.0270	0.0248	0.0231	0.0213



TABLE 3

The liquid mole fraction of gas-condensate for reservoir radius  $r = 0.5$  m for time: 1.5 h, 1.5 day, 10 days, 40 days, 4 months, 1 year, 2 years

TABLICA 3

Udział molowy fazy ciekłej układu gazowo-kondensatowego dla promienia złożowego  $r = 0,5$  m dla czasu 1,5 h, 1,5 dnia, 10 dni, 40 dni, 4 miesiące, 1 rok, 2 lata

T[K]	299.330	299.100	296.460	296.000	293.090	291.580	289.900
P[MPa]	9.45	9.34	8.90	8.64	8.52	8.325	8.11
Methane	0.4348	0.4311	0.4195	0.4102	0.4115	0.4068	0.4017
Ethane	0.0279	0.0279	0.0282	0.0282	0.0288	0.0291	0.0294
Propane	0.0307	0.0309	0.0320	0.0324	0.0335	0.0342	0.0350
n-hexane	0.5066	0.5101	0.5203	0.5292	0.5262	0.5299	0.5340

Table 2 and 3. The results are limited to the one phase flow e.g. only condensate saturation increase below the critical value.

#### 4. Conclusions

The Joule-Thomson effect is a main factor which influence on temperature changes of flowing fluid (eq.(5)). Temperature effect in the near-well zone may be considered as a additional skin-effect in the early-time analysis of transient gas well drawdown (or gas injection) tests with high constant rate at a wellhead. In the case of thin, non-isolated to the upper- and underburden reservoirs equation (5) must be modified for heat losses in vertical direction. In case of condensate reservoirs the high temperature drop may cause the additional retrograde condensation of heavier components of hydrocarbon mixture. The effect of retrograde condensation has been regarded in case of increase of condensate saturation up to the critical value. If the value of liquid saturation is greater than critical the flow must be considered as the two-phase flow, so this analysis is non applicable. The presented model of correction of condensate saturation rate is more suitable than full equilibrium model in the near-well zone.

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