PARES Petroleum and Reservoir Engineering Services Sdn. Bhd.

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Russian Neutron Log Interpretation

by

Harold L. Irby

INTRODUCTION

To perform various reservoir engineering and petrophysical evaluations of fields and prospects where the associated data is of Russian origin, both a qualitative and a quantitative capability in Russian derived measurements is desirable. The primary focus of this memorandum is to establish a procedure for utilizing Russian Neutron Logs in exploration, acquisition and development areas where such data has been recorded. The procedures presented here can be applied to other similar Russian log measurements and interpretation charts.

BACKGROUND

Several reports made by petroleum consultants concerning the Caspian Sea region make statements such as "A regression analysis some times gave acceptable results from the Russian Neutron." Apparently the assumption is that a linear response exists between neutron count rates in clean sands and 100% shales. Others have not attempted to utilize this basic petroleum well log measurement but have created a porosity curve based on functions of measured depth. Some have even made austere statements concerning the Caspian Sea region such as:

> "... the Miocene oil reservoir in question had a maximum structural porosity (PHIT) of 30%. The value of 30% was based on a typical world-wide value for Miocene deltaic, marginally cemented, offshore sands, e.g. the Niger Delta." [1]

The uncertainty in hydrocarbon in place computations using such approaches are indeterminable. The associated reservoir characterization resulting from these approaches are of a basic form only. Even with limited data improved analysis, characterization and procedures are achievable.

Conventional Russian log interpretation methodology has been to convert Russian derived measurements into "western" log equivalents and apply the quantitative analysis techniques developed, tested and applied during decades of petroleum industry experience. The term "western" is used loosely to describe logs recorded outside of the Former Soviet Union by such companies as British Plaster Board, Computalog, Halliburton, Schlumberger and Western Atlas and other similar wireline logging companies. To facilitate reservoir evaluation and characterization a procedure is described herein to utilize Russian log measurements and their corresponding charts in a manner suitable and compatible with the evaluations systems such as GeoFrame and Terrasciences.

DISCUSSION

Many log response charts involve an X component, a Y component and a Z variable with X and Y being either linear and/or logarithmic and Z having the characteristics of an overlying polynomial curve. For example, X = count rates, Y= porosity in limestone units and Z = hole diameter and the chart results is porosity in limestone units. For micrologs, X = ratio of the 2" normal resistivity to the mud cake resistivity, Y = ratio of the 1" inverse resistivity to the mud cake resistivity and Z = thickness of the mudcake with the result being flushed zone resistivity, Rxo. For lateral log resistivity devices, X= ratio of the AO electrode spacing to hole diameter, Y = ratio of the apparent resistivity to the mud resistivity and Z = ratio of true formation resistivity to the mud resistivity with the results being true formation resistivity, Rt.

Russian resistivity logs are typically recorded in Ohm-m, SP logs are in millivolts but gamma ray logs may be in but not limited to counts per second, counts per minute or other similar units. Sonic logs may be off by a factor of 2 and density logs may be run uncompensated for the effects of mud cake. Of

1 Williams, Fred G., Consultant, [text taken from] Appendix 3. 'Porosity from SP': Miocene oil field, Caspian Sea

particular importance in formation evaluation is the derivation of porosity from neutron logs which are recorded in counts per minute as opposed to being recorded in limestone porosity units as is customary with "western" type log recordings. Other applications of neutron logs include hydrocarbon delineation, in-situ fluid type and hydrocarbon saturation.

The Russian NGK60 neutron logging tool with a 60 cm source to detector spacing is commonly used neutron-gamma type device. The Russian logging company **BHNN** has a [possibly un-published] chart for the NGK60 tool and is attached herein and captioned **Puc 2**. This chart yields neutron porosity in limestone units as a function of counts per minute and borehole diameter in mm. Note that an 8.5" borehole diameter is 190 mm.

PROCEDURE

Each of the *n* caliper curves, for its range of count rate inputs, $\boldsymbol{x}$, can be modeled in the form of a polynomial of degree *m* , $P_i(\boldsymbol{x})$:

$$P_i(x) = A_i + B_i x + C_i x^2 + D_i x^3 + E_i x^4 + F_i x^5 + \cdots + X_i x^m \quad i = 1, n$$

If the Y-axis (e.g. for chart **Puc 2**, limestone porosity units) is logarithmic, then

$$P_i(x) = Log_{10}\left[P_i(x)\right] \quad i = 1, n$$

For every (e.g. counts per minute/1000) input value of $\boldsymbol{x}$, each of the *n* caliper curves and its associated borehole diameter can be designated as:

$$Z_i(x) = Z_i \quad i = 1, n$$

For a given input of $\boldsymbol{x}$, (e.g. counts per minute/1000) a function can be created between the caliper values, Z_i , and their corresponding porosity values, $P_i(\boldsymbol{x})$. Linear regression can then be applied to derive the limestone porosity as a function of both the caliper value Z and $\boldsymbol{x}$ as follows:

$$M_{(Z_i,P_i)}(x) = \left[\sum_{i=1}^{n}\left(Z_i * P_i(x)\right) - \frac{1}{n} * \left(\sum_{i=1}^{n} Z_i\right) * \left(\sum_{i=1}^{n} P_i(x)\right)\right] \div \left[\sum_{i=1}^{n} Z_i^2 - \frac{1}{n} * \left(\sum_{i=1}^{n} Z_i\right)^2\right]$$

$$B_{(Z_i,P_i)}(x) = \frac{1}{n} * \sum_{i=1}^{n} P_i(x) - M_{(Z_i,P_i)} * \frac{1}{n} * \sum_{i=1}^{n} Z_i$$

$$R_{(Z_i,P_i)}(x) = M_{(Z_i,P_i)}(x) * \sqrt{\left\{\left[\sum_{i=1}^{n} Z_i - \frac{1}{n} * \left(\sum_{i=1}^{n} Z_i\right)^2\right] \div \left[\sum_{i=1}^{n} P_i^2(x) - \frac{1}{n} * \left(\sum_{i=1}^{n} P_i(x)\right)\right]\right\}}$$

$$P_Z(x) = M_{(Z_i,P_i)}(x) * Z + B_{(Z_i,P_i)}(x)$$

Since the Y-axis is logarithmic for chart **Puc 2**, the Neutron limestone porosity as a function of the caliper value, Z, and, $\boldsymbol{x}$, (counts per minute/1000) is:

$$\Phi_{Neutron\,LS} = 10.0 ** P_Z(x) = 10.0 ** \left[M_{(Z_i,P_i)}(x) * Z + B_{(Z_i,P_i)}(x)\right]$$

R in the above equation is the correlation coefficient, M the regression coefficient, B the regression constant and R^2=R^2 = R**2 is the coefficient of determination.

APPLICATION

The data used for the polynomial curves and the polynomial curves derived are shown on the accompanying chart labeled **BHNN Puc 2**. Polynomial fits, $P_i(\boldsymbol{x})$, have been derived for each of the borehole diameter curves. Two additional borehole diameter curves, 160 mm and 100 mm, have been interpolated to facilitate the porosity derivation procedure (i.e. to add some more points for the linear regression). The regression coefficient of determination, R^2, is greater than 0.9990 for each $P_i(\boldsymbol{x})$.

When the above procedure is applied for chart BHNN Puc 2., the numerical value of n changes as a function of the count rates, $\boldsymbol{x}$, and the caliper values, Z_i . Consequently the number of polynomials, $P_i(\boldsymbol{x})$, available for the linear regression diminishes as the count rate increases and in essence n becomes a smaller and smaller number. An arbitrary cut off value for changing the value of n has been assigned at approximately 0.02 limestone porosity units for each of the polynomial curves. This dependency on the number of caliper values implies a discontinuity in the $P_z(x)$ function. The effect of this discontinuity is very small and is far less than the statistical variations observed on neutron count rate logs. This effect is illustrated in the accompanying graph labeled "**Discontinuity Illustration for BHNN Chart Puc 2**" and is plotted for only one borehole diameter curve of 160 mm. It can be seen that the discontinuity is most pronounced at high count rates, i.e. at very low porosity values. At lower count rates and higher porosity values the discontinuity is non-discernible.

The various polynomial functions for chart BHNN Puc 2 and the above procedure have been incorporated into a FORTRAN subroutine and is included herein. The subroutine should easily be incorporated into the GeoFrame or Terrasciences environments presently available. No detailed description of the subroutine is given here but it is analogous to the equations presented in the text of this memorandum. An interactive program, NEUTPUC2.EXE is available from the PCSB Development Petroleum Engineering Formation Evaluation Department and is a practical application of chart BHNN Puc 2.

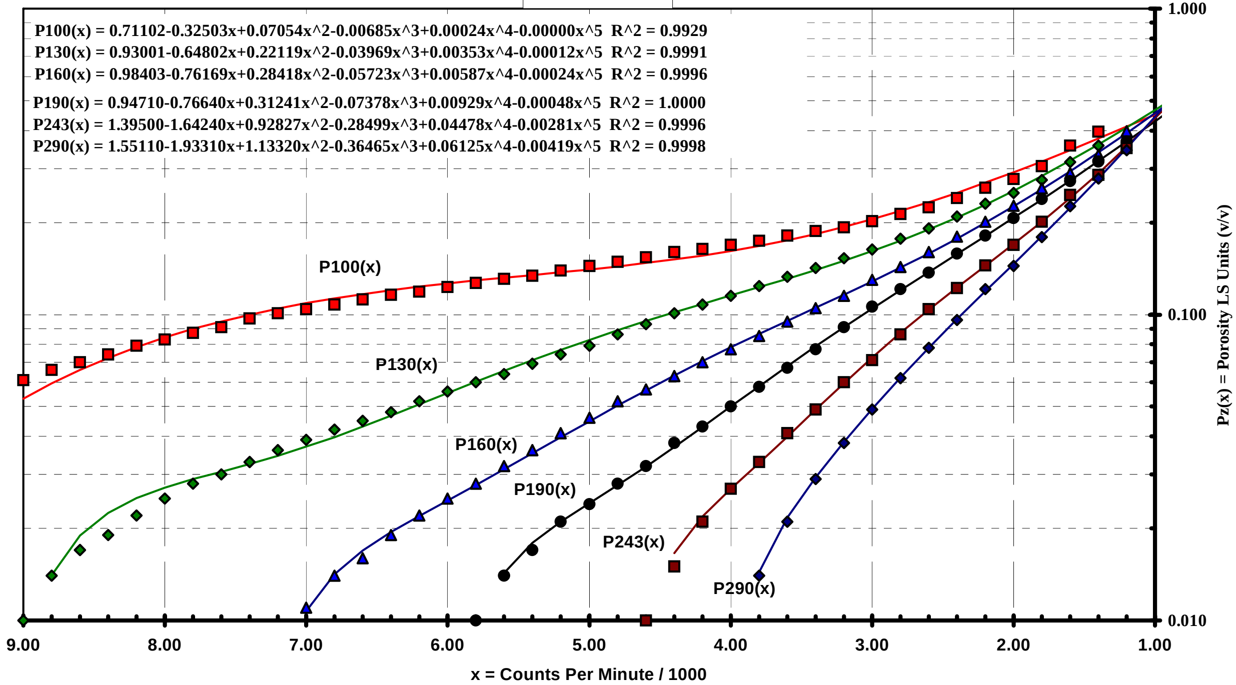
CONCLUSION

Although this memorandum illustrates the procedure and application for the NGK-60 neutron log response, the procedure can be applied to a variety of logging tools and their corresponding physical response charts. Consistent application of basic physical principles when interpreting/applying Russian log data should yield better results than those that have been observed previously. The results presented herein will be incorporated into the exploration, acquisition and development efforts of Petronas Carigali in the areas of the Former Soviet Union and/or those countries where Russian logging tools have been run in wells that may come to ones attention. [2]

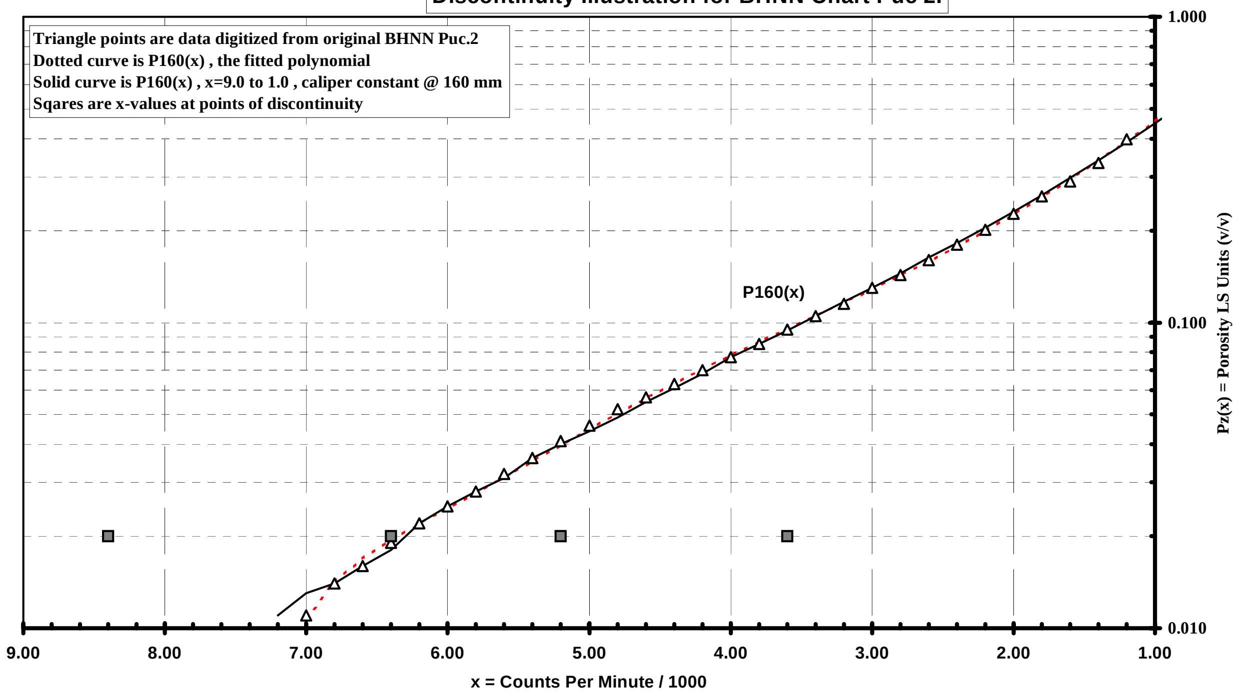
[2] Following is a listing of the FORTRAN subroutine. Also included in this memorandum are graphs labeled **BHNN Puc 2**. , and **Discontinuity Illustration for BHNN Chart Puc 2**. and represent Russian neutron log chart captioned **Puc 2**. , respectively.

```
C   This subroutine program is designed to compute porosity as per Russian neutron log chart Puc.2
C   The logging company is BHNN; the logging tool is NGK-60.
C   Program author:  Harold L. Irby
C
      SUBROUTINE NEUTPUC2 (CPM,CAL,PNLS)
      INTEGER JJ, KK
      REAL PNLS,CPM,CAL,SL, BB, RR, RK
      REAL PP(6), ZZ(6), TT(6)
      REAL SUMZ, SUMP, SMZP, ZSQR, PSQR
      REAL A(6), B(6), C(6), D(6), E(6), F(6)
      DATA A(1),B(1),C(1),D(1),E(1),F(1)
     1 /1.5511E+0,-1.9331E+0,1.1332E+0,-3.6465E-1,6.1251E-2,-4.1862E-3/
      DATA A(2),B(2),C(2),D(2),E(2),F(2)
     1 /1.3950E+0,-1.6424E+0,9.2827E-1,-2.8499E-1,4.4783E-2,-2.8085E-3/
      DATA A(3),B(3),C(3),D(3),E(3),F(3)
     1 /9.4710E-1,-7.6640E-1,3.1241E-1,-7.3778E-2,9.2933E-3,-4.7592E-4/
      DATA A(4),B(4),C(4),D(4),E(4),F(4)
     1 /9.8403E-1,-7.6169E-1,2.8418E-1,-5.7231E-2,5.8654E-3,-2.3912E-4/
      DATA A(5),B(5),C(5),D(5),E(5),F(5)
     1 /9.3001E-1,-6.4802E-1,2.2119E-1,-3.9693E-2,3.5339E-3,-1.2289E-4/
      DATA A(6),B(6),C(6),D(6),E(6),F(6)
     1 /7.1102E-1,-3.2503E-1,7.0537E-2,-6.8489E-3,2.3575E-4,-0.0000E-0/
       DATA ZZ(1),ZZ(2),ZZ(3),ZZ(4),ZZ(5),ZZ(6)
     1 / 290, 243, 190, 160, 130, 100  /
       DATA TT(1),TT(2),TT(3),TT(4),TT(5),TT(6)
     1 / 3.6, 4.2, 5.2, 6.4, 8.4, 10.4 /
C    ZZi are the caliper chart values  TTi are the limits at .02 ls v/v
C    Ai, Bi, Ci, Di, Ei, Fi, are the constants in the polynomial equation, Pi(x)
        CPM  = CPM/1000.0
        KK = 6
        JJ = 1
        DO 330 K=JJ,KK
        IF (CPM .GE. TT(K)) JJ = K + 1
330   CONTINUE
        SUMZ = 0.
        SUMP = 0.
        SMZP = 0.
        ZSQR = 0.
        PSQR = 0.
        IF (KK-JJ .GE. 1) THEN
        DO 331 K = JJ,KK
        PP(K)=A(K)+B(K)*CPM+C(K)*CPM**2.+D(K)*CPM**3.+E(K)*CPM**4.+F(K)*CPM**5.
        PP(K) = LOG10(PP(K))
        SUMZ = SUMZ + ZZ(K)
        SUMP = SUMP + PP(K)
        SMZP = SMZP + ZZ(K)*PP(K)
        ZSQR = ZSQR + ZZ(K)**2.
        PSQR = PSQR + PP(K)**2.
331   CONTINUE
        RK = REAL(KK - JJ + 1)
        SL = (SMZP - (1/RK)*SUMZ*SUMP)/(ZSQR - (1/RK)*SUMZ**2.)
        BB = (1/RK) * SUMP - SL * (1/RK) * SUMZ
        RR = SL*((ZSQR-(1/RK)*SUMZ**2.)/(PSQR-(1/RK)*SUMP))**.5
        PNLS = 10.**(SL * CAL + BB)
        ELSE
        DO 332 K=KK
        PP(K)=A(K)+B(K)*CPM+C(K)*CPM**2.+D(K)*CPM**3.+E(K)*CPM**4.+F(K)*CPM**5.
        PNLS = PP(K)
332   CONTINUE
        ENDIF
        RETURN
        END
```

BHNN Puc 2.



Discontinuity Illustration for BHNN Chart Puc 2.



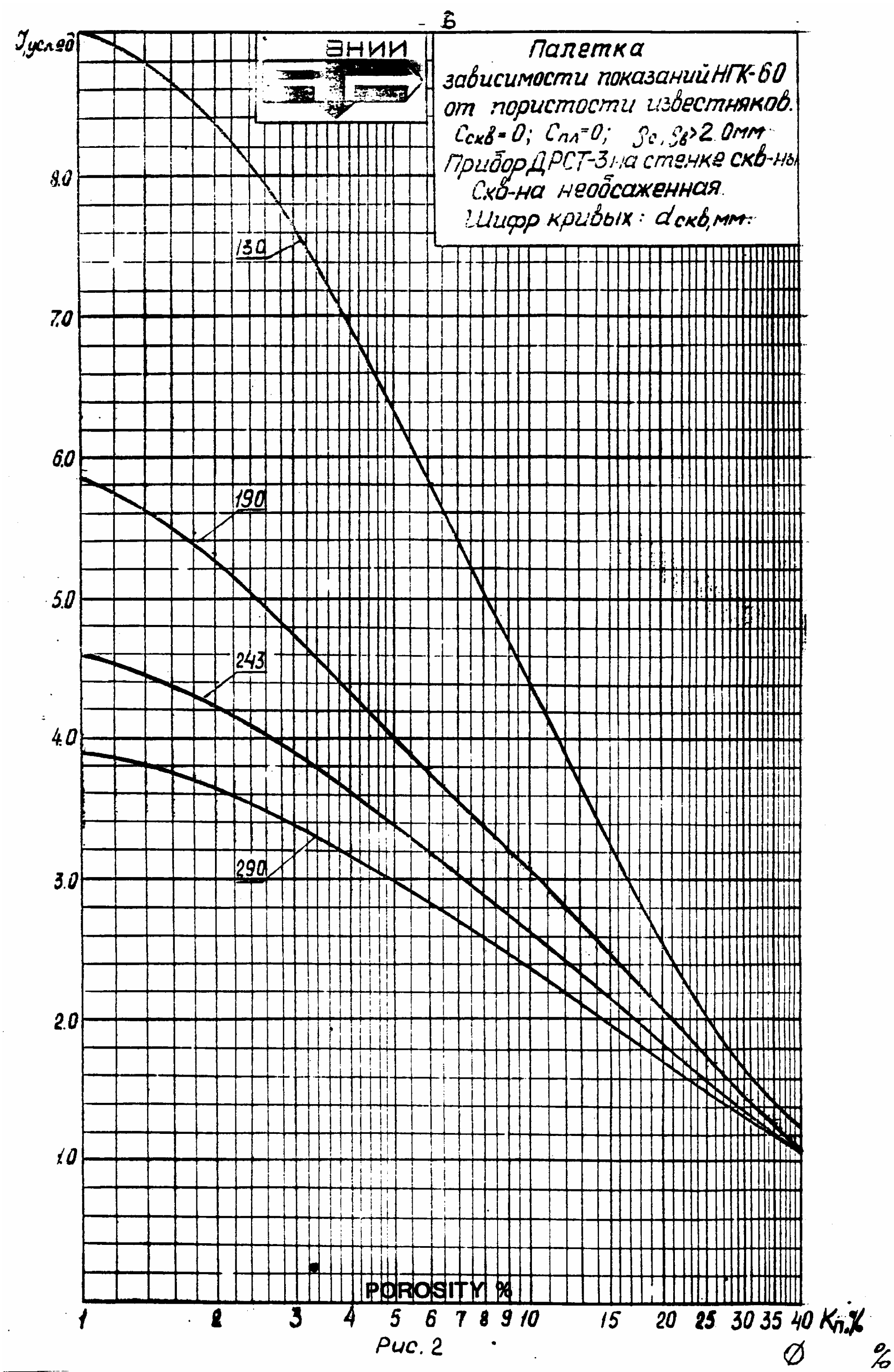

Б
ЗНИИ
Палетка
зависимости показаний НГК-60
от пористости известняков.
Сскв = 0; Спл = 0; δс, δв > 2.0мм
Прибор ДРСТ-3 на стенке скв-ны
Скв-на необсаженная.
Шифр кривых : dскв, мм.
Jусл.ед
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
130
190
243
290
POROSITY %
1
2
3
4
5 6 7 8 9 10
15
20 25 30 35 40 Kп,%
Ø
%

Рис. 2