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IDENTIFICATION OF PRODUCTION WELL FLOW REGIME AND OIL-GAS-WATER PHASES FLOW MEASUREMENT

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The combination of hydrostatical and cross-correlation methods for in-line flow phase composition determination has been proposed. Production well flow regime identification is realized by artificial neural network processing of acoustical and differential pressure pulsation signals symbolization. Differential pressure values between top and bottom points of the flow cross section in pipeline has been used for liquid hold-up measurement. An improved impedance method has been used for watercut determination. The hell of the betterment is made up of the special structure flowcell development. Separate phases flow velocities has been determined in consequence of acoustical signals wavelet and cross-correlation processing. It has been realized by means of the designed data processing algorithms for discrete wavelet transformation and signal decomposition by digital signal processors. Device design has been developed for an on-line production well control and extraction hydrocarbon wells optimization in the field environment.

Keywords: *flow regime identification, wavelet, production well, flow measurement, multiphase flow*

1. INTRODUCTION

Flow regime identification and multiphase flow measurement of production wells increasingly occupy attention of researchers and field engineers. This interest has increased considerably during recent years due to applications to new processes in petroleum production and refining. One prominent example of multiphase phase flow is provided by the gas lift process where oil, water and gas flow simultaneously [1, 2]. In-line real-time multiphase measurements are providing new capabilities in reservoir management and production optimization. It has been shown that the quality of measurements can have a significant impact on the back allocation of production to individual wells or fields; information that is critical in reservoir simulation history matching, field management and reserves estimation [3]. Data also provides the basis for important operational decisions, such as when to shut-in a high water-cut well and planning workovers/recompletions [4]. During the last years, the focus on slug control has increased in the oil industry too. The main reason is that many oil fields are at the end of their lives, and that the ratio of oil, gas and water changes. Hence, the existing production pipelines are not optimal with respect to the new compositions, and thereby slugging occurs [5]. There are several kinds of slugging, including terrain slugging, riser slugging and hydrodynamic slugging. This slugging can be identified by in-line real-time measurements of pressure, phase volume fractions and flow regime identification**.** For an introduction to slug generating mechanisms and how OLGA simulates these phenomena, see [6]. All the above has substantiated the expedience of obtaining data about multiphase flow regime of the production well and separate phases flow rates.

At the same time the fluids produced from oil or gas wells are rarely purely liquid or gaseous hydrocarbon mixtures. Usually, the fluid emerges as a multiphase mixture. In its simplest from, this is a mixture of natural gas and oil but, in many systems, water is present as are a variety of solid phases (sand, hydrates and asphaltenes) [7]. In contrast to the case of single-phase flow, because the constituents of multiphase flow vary in their physical properties (density, viscosity, chemical composition, etc.), describing multiphase flow characteristics is usually quite difficult. One typically identifies the various ways in which the constituents travel through the pipe in terms of their flow regime (geometrical distribution in space and time of the individual phase components) [8]. Flow regime is not only a function of the relative proportions of the individual constituents, but to other factors such as orientation of the pipe and the velocities of flow phases, among others. An additional point to emphasize is that fluid may exist solely as a vapor (gas), solely as a liquid, or as a mixture of both, because pressure and temperature conditions may differ at various locations along the flow path between reservoir and points downstream gas and liquid. The overview of actual multiphase flow measurement system has represented in papers [2, 3, 4, 7, 8]. But that systems aren't all service, therefore development new measurement system is expedient.

2. MEASUREMENT ALGORITM

Multiphase flow rate (for gas-liquid mixture well flow**)** is determined from equation :

$$Q=Q_G+Q_C+Q_W=U_G\times A_G+U_C\times A_C+U_W\times A_W\,. \tag{1}$$

The observations confirm the statement that liquid phase velocities is approximately equals to one another, because them densities is approximately equals to one another too. Therefore:

$$U_L = U_C = U_W \qquad (2)$$

If pipe cross sectional area is A, and $A_G = A - (A_C + A_W)$, then equation (1) is written:

$$Q = Q_G + Q_L = U_G \times \left(A - (A_C + A_W)\right) + U_L \times \left(A_C + A_W\right) \qquad (3)$$

2.1. Measurement liquid hold-up

The paper [9] presents method and evaluation algorithm for liquid hold-up estimation in three phase flow (gas-water-condensate or gas-oil-water). The principle of method consists in the following. For simplicity, we separate in spirit the flow spacing inside of the duct. This flow spacing has cylinder form. Cylinder height l is 0,01 m and base circle diameter D_{vn} is equaled to inside duct diameter. Cylinder alignment is horizontal, viz flow spacing axis is parallel to the skyline. We perform the weighing that flow spacing by dint of the differential manometer with the fast response. Measurement is executed between top and bottom points of chosen flow spacing (fig. 1).

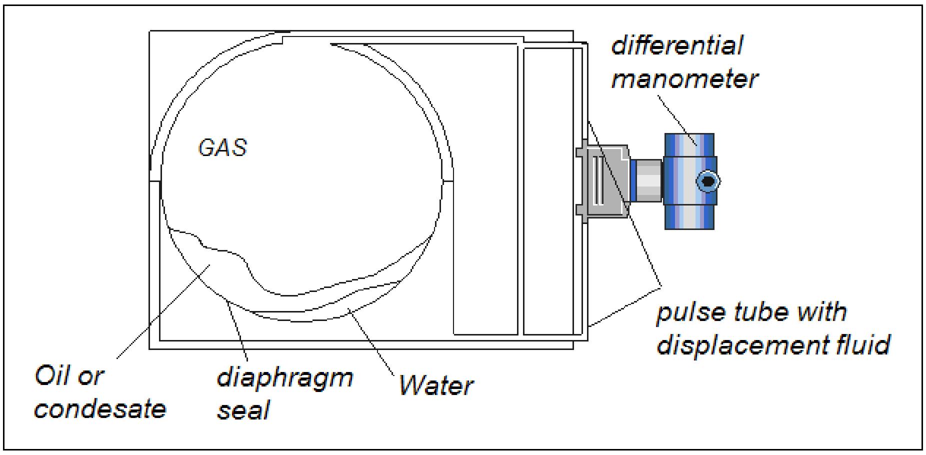

Figure 1. Schematic drawing of the interflanged insert insertion piece design for liquid hold-up measurement

The advantage that measuring procedure consist in the possibility to measure under high static pressures in ducts. It should be appreciated that gas density ρ_G even for high pressure (to 20 MPa) is three times less than liquid's density. In site gas phase density is used for the differential pressure P_{dif} *value* correction. Because oil or condensate and water density are the known, we can to evaluate the liquid hold-up with following expressions. Equivalent height fluid duct level h_L evaluates on the ground of measured differential pressure P_{dif} between top and bottom points of duct with flow:

$$h_L = \frac{P_{dif}}{(\rho_L \cdot g)}, \tag{4}$$

where ρ_L [7]:

$$\rho_L = \left(1 - \frac{A_L}{A}\right) \cdot \rho_G + \left(\frac{A_L}{A}\right) \cdot \left[C_w \cdot \rho_w + \left(\left(1 - C_w\right) \cdot \rho_C\right)\right].$$

With the aim of the phase voids calculation, it is expedient to perform the estimation of wet duct perimeter S_L. That part of duct cross-section perimeter is moistened with the liquid phases :

$$S_L = D_{vn} \times \arccos\left(1 - \frac{2h_L}{D_{vn}}\right). \tag{5}$$

The contact between liquid and gas flow phases take place along the duct cross-section chord length S_{GL}:

$$S_{GL} = 2 \times \sqrt{h_L \cdot D_{vn} - h_L^2} \tag{6}$$

Occupied liquid phase duct cross sectional area A_L is:

$$A_L = \frac{\left(S_L \times \left(\frac{D_{vn}}{2}\right) - S_{GL} \times \left(\frac{D_{vn}}{2} - h_L\right)\right)}{2}. \tag{7}$$

Consequently, cross sectional areas that occupied gas A_G, water A_W and condensate A_C phases is followed:

$$A_G = A - A_L, \tag{8}$$

$$A_W = C_W \times A_L, \tag{9}$$

$$A_C = A_L - A_W. \tag{10}$$

The data about differential pressure in a flow cross sectional in two points (on the fixed spacing interval one from other) in pipeline has been used for liquid hold-up measurement. The combination of hydrostatical and cross-correlation methods for in-line flow liquid phase composition determination has been used.

2.2. Measurement flow watercut

It is necessary to know flow watercut C_W for all cross sectional areas determination. An improved impedance method is used for watercut determination. The electrical impedance of multiphase flow varies with the concentration and distribution of the phases. The use of impedance measurement as a means of characterising flow is attractive because it gives a virtually instantaneous response [13, 14, 15]. We is measured impedance: 1) between electrodes based in the flow and 2) beetwen electrodes based in the flow (cut longitudinally inner pipe) and external pipe wall. The hell of the betterment is made up of the special structure flowcell development (fig. 2).

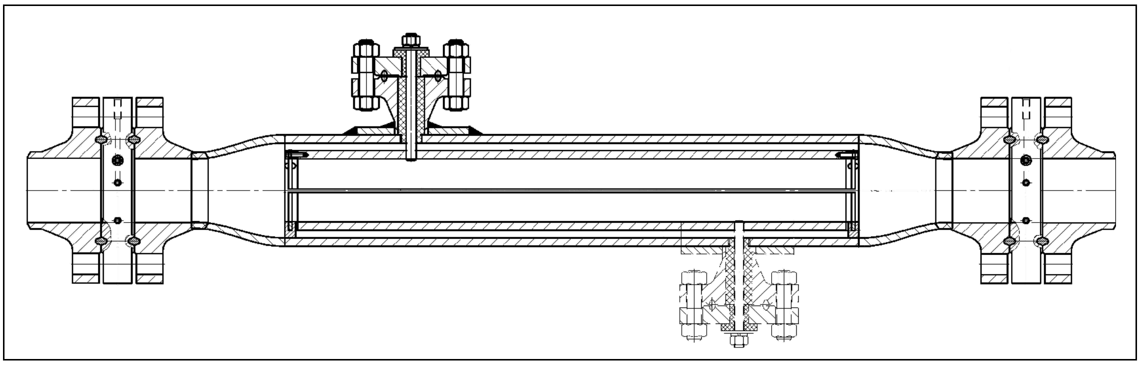

Figure 2. General assembly drawing of flowcell structure

The flowcell design is provided increased device sensibility in consequence of in-line separation towards high gas void fraction multiphase flows. The impedance is measured governed by both conductance and dielectric conductance in our system. A major problem with the impedance method is that it can be highly sensitive to the flow pattern within the channel [7]. This is illustrated by the results shown in [10], which compares the output capacitance as a function of void fraction for annular flow and stratified flow stimulations with the ring electrodes. Although curves calculated by Bouman et al what is shown in [11] are extreme cases and actual results on the impedance method tend to be somewhat less sensitive than indicated there , the flow regime sensitivity is always a potential problem with this technique.

In summary, there are some difficulties associated with its use in multiphase flowmeter [7]:

1. the measured impedance is likely to be a function of both phase fraction and phase configuration. If the configuration is not known a priori, then the phase fraction cannot be determined unambiguously;

2. electrical impedance methods based on capacitance measurements are suitable for oil-continuous mixtures, while conductivity measurements are suitable for water-

continuous mixtures. As the flow passes through a meter, it is possible that the mixture switches from oil-continuous to water-continuous, which requires a switch in impedance method. If the impedance sensor's response to the phase inversion process is not sufficiently fast, a measurement uncertainty may be induced. The exact inversion point for an oil–water mixture is not known a priori, as it varies with the fluid properties and the current flowing conditions.

To resolve first difficulty we have developed the flowcell structure design with in-line flow partition for annular and stratified flow patterns. The flowcell structure design provides the multiphase flow partition in two parts: 1) mainly liquid oil-water flow between pipe well and inner pipe; 2) mainly gas flow with liquid droplets inside cut longitudinally inner pipe. The flowcell design is provided increased device sensibility in consequence of in-line separation towards high gas void fraction multiphase flows.

To resolve second difficulty we have used high precision impedance converter system solution at the base IC AD5934. The AD5934 can accurately measure a range of impedance values to less than 0.5 % of the correct impedance value [12]. It is a system solution which combines an on-board frequency generator with a 12-bit, 250 kSPS, analog-to-digital converter (ADC) (fig. 3). The frequency generator allows an external complex impedance to be excited with a known frequency. The response signal from the impedance is sampled by the on-board ADC and a discrete Fourier transform (DFT) is processed by an on-board DSP engine. The DFT algorithm returns a real (R) and imaginary (I) data-word at each output frequency. We use test signals in the frequency band from 5000 to 95000 Hz with frequency step 180 Hz.

The sensor signal hodograph (Re-Im) form is changed at various flow watercut values of the flowcell structure impedance sensor (fig. 4). Experimental values of the impedance hodographs (Re-Im) is kept in the microprocessor memory at tabular style for every flow well and for watercut representative values them. The well flow watercut instantaneous values is defined from the memory table searching and them table data interpolation.

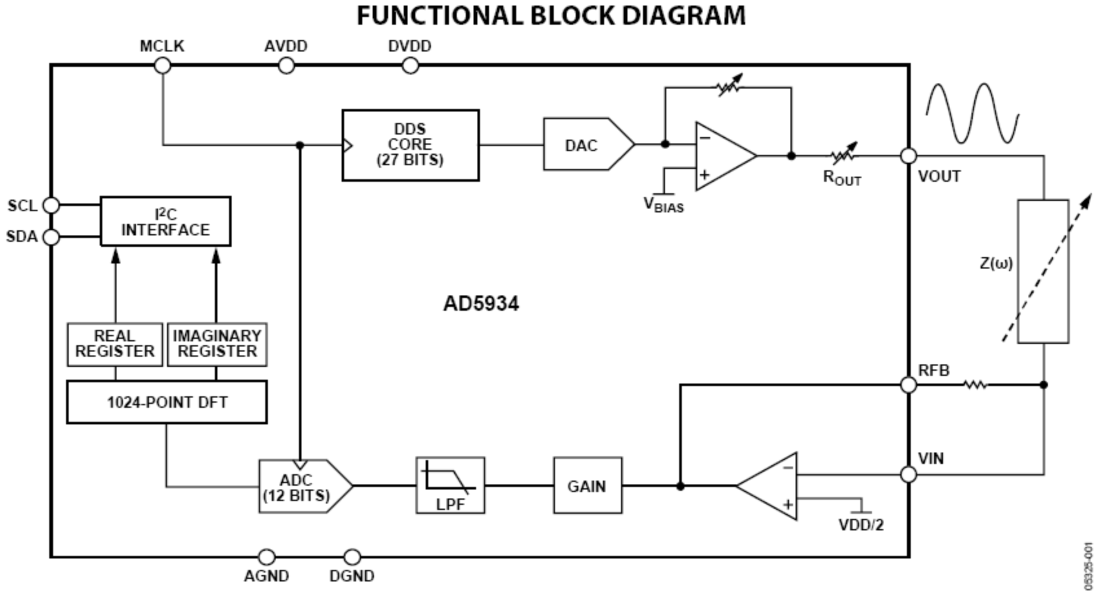

Figure 3. Functional block diagram impedance converter system (Z(ω) – impedance sensor)

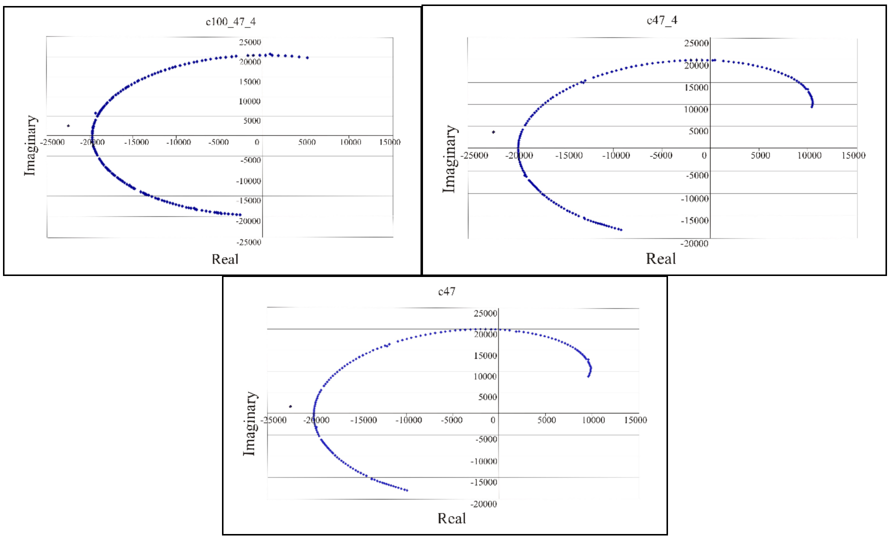

Figure 4. Hodograph (Re-Im) of the flowcell structure sensor signal impedance at various flow watercut values (eq capacity change: 147 pF, 51 pF, 47 pF)

2.3 Well flow regime identification

Production well flow regime identification is realized by artificial neural network (ANN) processing of acoustical and differential pressure pulsation signals symbolization. We have used a new approach for analyzing complex measurements known as data symbolization [16]. Briefly, data symbolization transforms an original series of measurements into a limited number of discrete symbols. The resulting symbol series is then analyzed for nonrandom temporal patterns. For our purposes, we are specifically interested in identifying and measuring repeating unstable patterns which continue to come and go even when the flow parameters are kept fixed. We have used the multiphase flow acoustical noise signals as input data for the data symbolization. Ten sequence code frequency values ($X_1 \ldots X_{19}$) is input date for the artificial neural network structure. ANN outputs is flow regime binary code (annular, stratified, slug or transient) (fig. 5).

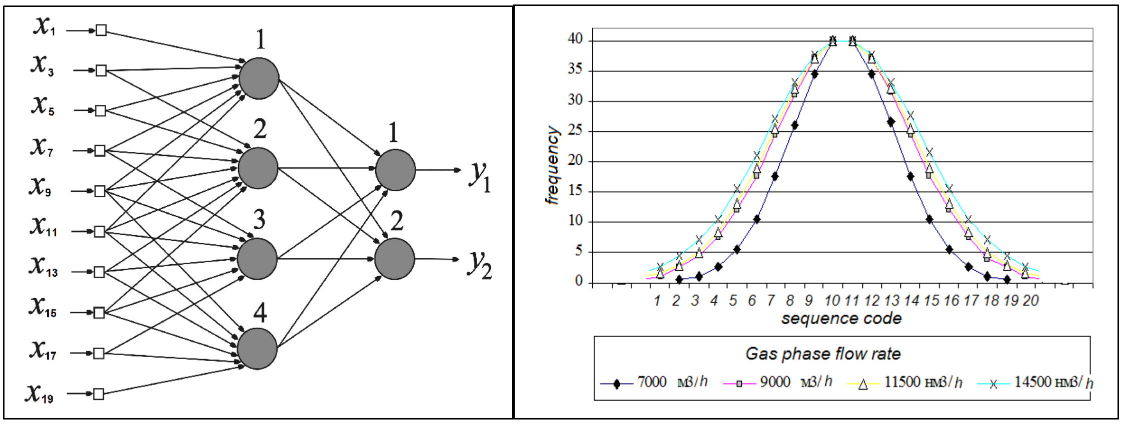

Figure 5. Artificial neural network structure
and symbolization results as input for this network

A particular attribute of an ANN is its high prediction accuracy when used with metering devices. The chosen ANN for our system is a multilayer perceptron 10-4-2. The each unit perform a biased and weighted sum of their inputs and pass this activation level through a transfer function to produce their output, and the units are arranged in a layered feed-forward topology. We have used as best-known ANN training algorithm as error back-propagation algorithm. The results presented by [17] showed predictions with a root mean square error of 7 % and 10 % for the slug or transient and annular or stratified, respectively.

2.4 Phase velocities determination

Every phase flow velocities has been determined in consequence of acoustical signals wavelet transformation and cross-correlation processing. Acoustic cross-correlation is a technique for determining the velocity of flow phases in a pipe by measuring the temporal acoustical fluctuations in the multiphase flow. It is based on the assumption that the fluctuations in the signals are caused by gas bubbles and turbulent liquid eddies which travel down the pipe at the same velocity as the fluid phases. The signal at the downstream sensor at time t is therefore related to the signal at the upstream sensor recorded at an earlier time, $t - t_m$, where t_m is the time taken for the fluid to traverse the distance, L, between the acoustic sensors. The aim is to calculate t_m (for every phase t_G and t_L) and hence the gas velocity U_G and liquid velocity U_L:

$$U_G = \frac{L}{t_G}\,;\; U_L = \frac{L}{t_L}\,. \tag{11}$$

Cross-correlation function discrete values of signal wavelet approximation C_m^{An} and detalization C_m^{Dn} on n decomposition levels:

$$C_m^{An} \equiv C^{An}(\Delta tm) = \frac{1}{N-m} \sum_{k=0}^{N-m-1} a1_k^n \cdot a2_{k+m}^n\,, \tag{12}$$

$$C_m^{Dn} \equiv C^{Dn}(\Delta tm) = \frac{1}{N-m} \sum_{k=0}^{N-m-1} d1_k^n \cdot d2_{k+m}^n\,, \tag{13}$$

$$t_G = \max_{n=1}^{N/2}\left(C_m^{Dn}\right);\; t_L = \max_{n=1}^{N/2}\left(C_m^{An}\right)\cdot \tag{14}$$

It has been realized by means of the designed data processing algorithms for discrete wavelet transformation and decomposition of informative signal by digital signal processors [18].

3. EXPERIMENTAL TESTING FACILITIES

The offered method has been investigated and has been tested on the designed laboratory multiphase flows simulation facility (fig. 6). This facility has consisted of (sunwise); high pressure cylinder 1; gas pressure regulator 2; shutoff cocks 3, 4; increaser 5, 7, 10, 16; gas meter 6; gas-liquid mixture formation duct 8; liquid injection unit 9; liquid sampling valves 11; glass duct 12, 15; insertion piece with impedance sensor 13; experimental duct with hydrostatic and acoustic transmitters 14; process pipeline 17; backward pressure adjustment tap 18; mixture flow rate adjustment tap 19; sewage disposal tap 20; gravity separator 21; liquid flowmeter 22.

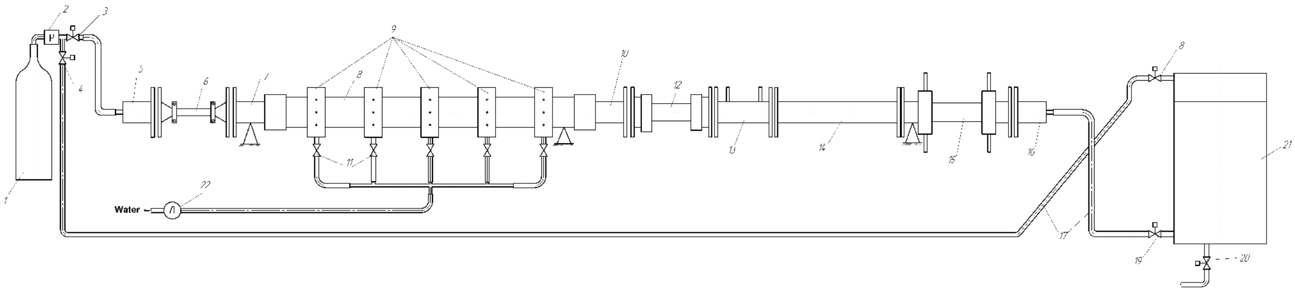

Figure 6. Laboratory multiphase flows simulation facility

Device design has been developed for an on-line production well control and extraction hydrocarbon wells optimization in the field environment. Pipe layout of field test facility manifold at sea offshore production field MCP-17 public company "Chornomornaftogaz" Ukraine is represented in fig. 7 and fig. 8 (photo). There is performing the field tests of developmental flow regime identification and multiphase flow measurement system now.

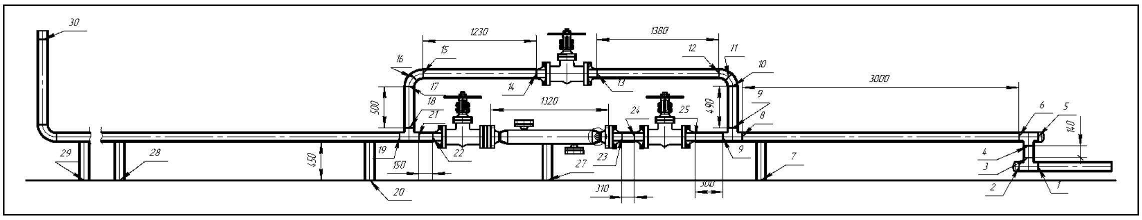

Figure 7. Pipe layout of field test facility manifold
(sea offshore production field MCP-17
public company "Chornomornaftogaz" Ukraine)

Figure 8. Photo of the pipe layout of field test facility manifold

CONCLUSION

It has been proposed to realize well flow regime identification by artificial neural network processing of acoustical and differential pressure pulsation signals symbolization. Differential pressure values between top and bottom points of the flow cross section in pipeline has been used for liquid hold-up measurement. An improved impedance method has been used for watercut determination. Every phases velocities has been determined on the basis of acoustical signals wavelet and cross-correlation processing. It has been realized by means of the designed data processing algorithms for discrete wavelet transformation and signal decomposition by digital signal processors. Device design has been developed for an on-line production well control and extraction hydrocarbon wells optimization in the field environment.

SYMBOLS

Q_G, Q_C, Q_W – gas, oil or condensate, water phase flowrates, consequently ;

U_G, U_C, U_W – gas, oil or condensate, water phase velocities, consequently ;

A_G, A_C, A_W – gas, oil or condensate, water phase occupied in site duct cross sectional areas, consequently;

D_{vn} – inner duct diameter ;

Δt – signal sampling period; $m = 0, 1,\ldots,(N-1)$ – shift between counts two signal quantity (eq τ for continuous cross-correlation function);

k – signal count number in sample; N – sample volume ;

$a1^n$ and $a2^n$ – first and second decomposition result value (approximation) on n decomposition level consequently;

$d1^n$ and $d2^n$ – first and second decomposition result value (detalization) on n decom position level consequently.

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