Measurement 51 (2014) 34–41

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Precise volume fraction prediction in oil–water–gas multiphase flows by means of gamma-ray attenuation and artificial neural networks using one detector

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ARTICLE INFO

Article history:
Received 1 August 2013
Received in revised form 25 December 2013
Accepted 21 January 2014
Available online 29 January 2014

Keywords:
Artificial neural network
Gamma-ray attenuation
MCNP
Multiphase flow-prediction

ABSTRACT

Artificial neural network (ANN) is an appropriate method used to handle the modeling, prediction and classification problems. In this study, based on nuclear technique in annular multiphase regime using only one detector and a dual energy gamma-ray source, a proposed ANN architecture is used to predict the oil, water and air percentage, precisely. A multi-layer perceptron (MLP) neural network is used to develop the ANN model in MATLAB 7.0.4 software. In this work, number of detectors and ANN input features were reduced to one and two, respectively. The input parameters of ANN are first and second full energy peaks of the detector output signal, and the outputs are oil and water percentage. The obtained results show that the proposed ANN model has achieved good agreement with the simulation data with a negligible error between the estimated and simulated values. Defined MAE% error was obtained less than 1%.

1. Introduction

Multiphase flow measurement is a matter of high importance in oil and gas industry, especially in applications such as reservoir management, field development, operational control, flow assurance and production allocation [1]. By determining volume fractions of oil–water–gas in oil productions in combination with velocity measurement of each phase, the mass flow rate can be determined, which is a useful parameter for monitoring the productions. Utilizing nuclear techniques such as neutrons [2,3] and gamma ray [4–9], because of their ability to measure volume fractions without modifying the operational conditions and being non-invasive, is so useful. For the first time, Abouelwafa and Kendall [4] proposed a multi-energy gamma attenuation technique to resolve three-phase mixture component ratios. They examined various static mixture of oil–water–gas in a 0.1 m diameter pipe section using cobalt-57 (122 keV) and barium-133 (365 keV) radioisotopes and a lithium-drifted germanium based detector. Li et al. [10], also analyzed static mixtures in a cubic conduit using americium-241 (59.5 keV) and cesium-137 (662 keV) radioisotopes and a sodium iodide detector crystal. Tjugum et al. [11], produced a multi-beam gamma-ray instrument with an americium-241 source and three detectors. Two detectors, measured gamma ray attenuation across the pipe flow, while the third one measured the scattered radiation. The obtained results were more accurate than single beam. Generally, one of the difficulties in this field is the mathematical modeling to correlate the measurements with volume fractions. In such situations, artificial intelligence techniques, especially artificial neural networks (ANN) can be so helpful. Many researchers have

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http://dx.doi.org/10.1016/j.measurement.2014.01.030
0263-2241/

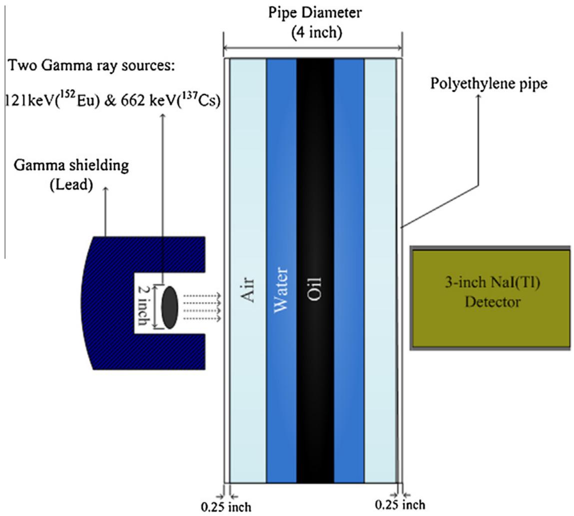

Fig. 1. Schematic of simulated setup configuration in MCNP4C code.

used these techniques in gamma densitometry [7,12–14,16] in order to overcome such difficulties. Cong et al. [17] reviewed applications of ANNs in flow and heat transfer problems in nuclear engineering. In 2009, Salgado et al. [13] proposed a methodology based on neural network to predict volume fractions. They simulated a system comprised of three detectors (one of them for transmitted gamma rays and two of them for scattered) and dual energy gamma-ray source (Eu-152 with energy 121 keV and Ba-133 with energy 356 keV) using N-particle (MCNP) code. In this work, following their investigation, a system with MCNP code has been simulated, which number of detectors was reduced from three to just one detector and only transmitted gamma-rays were considered. Advantage of using less detectors, is the costs decrement as an important criterion in industry. Also it can make the operation of the system easier. When the input of ANN is a signal, one of the most important points is how to choose the features as the ANN inputs. In previous works [13,14], 58 and 106 features using two and three detectors were considered as ANN inputs respectively. But in this study, only two features using one detector were selected. Our attention was concentrated on improving the precision of volume fractions prediction in annular regimes with only one detector using artificial neural network.

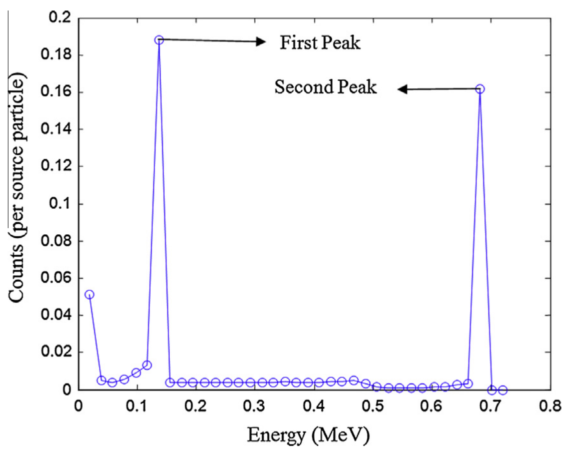

Fig. 2. A sample signal of detector output when oil = 0%, water = 20% and air = 80%.

2. Methodology

2.1. Simulation results

The first step in this investigation was the Monte Carlo simulations in order to generate the training and testing

Table 1
Simulation results for different oil and water percentages using MCNP4C code.

Oil percentage	Water percentage	First peak	Second peak
3	36	0.129292	0.129547
4	13	0.207251	0.170824
5	79	0.072056	0.091089
5[a]	62	0.087778	0.102509
6	6	0.249122	0.189457
7	5	0.249827	0.189753
8	4	0.250524	0.190041
8	35	0.122628	0.125515
9	13	0.182822	0.159061
10	21	0.151263	0.14234
12[a]	10	0.184102	0.159666
12	16	0.161123	0.147744
13	34	0.116502	0.121671
15	10	0.172789	0.153869
18	34	0.109335	0.117071
19	26	0.121461	0.124723
20	19	0.133975	0.132263
21	3	0.178791	0.156708
23	65	0.071203	0.09054
25	14	0.135143	0.132788
25[a]	38	0.095453	0.10782
26[a]	38	0.094397	0.107091
26	48	0.083617	0.09958
26	71	0.065141	0.085879
30	67	0.065514	0.086127
32	3	0.146171	0.138708
32	7	0.1365	0.133214
33	15	0.118633	0.122532
34	18	0.112071	0.11841
34[a]	19	0.110497	0.117415
35[a]	59	0.068014	0.087997
35	62	0.065972	0.086411
40[a]	60	0.064453	0.085056
46[a]	43	0.072628	0.091126
47	17	0.096871	0.108292
47	24	0.088968	0.102898
47	28	0.084902	0.100047
49[a]	18	0.093517	0.106011
53[a]	18	0.089443	0.103185
60	22	0.079446	0.096054
61[a]	36	0.068084	0.087425
75	8	0.080493	0.09676
78	17	0.070508	0.089146
79	11	0.075041	0.09266
80[a]	14	0.071709	0.090065
80[a]	15	0.07088	0.08941
85[a]	12	0.071531	0.089792
96	2	0.096843	0.109003
96[a]	3	0.103984	0.114392
97	3	0.10693	0.116571

[a] These data will be used for testing the ANN model in next section. The others will be used for training.