A ROBUST MODELING APPROACH FOR FRICTIONAL PRESSURE LOSS CALCULATION OF THREE PHASE FLOW IN INCLINED ANNULI

Authors

Arya Shahdi
Department of Petroleum Engineering, Islamic Azad University, Science and Research Branch, Tehran, Iran

Milad Arabloo
Department of Petroleum Engineering, Petroleum University of Technology, Ahwaz, Iran

Introduction

* Data

This article is written based on a comprehensive and precise experimental data obtained from an actual well (Osgouei and Ozbayoglu 2013). Extensive experiments were conducted at a cutting transport flow loop using air-water mixtures under a wide range of flow rates, rate of penetration (ROPs), pipe rotations and hole inclinations.

Table 1: Descriptive statistics of the applied data sets

Parameter	Minimum	Maximum	Mean
ROP	80	120	98.52
RPM	0	120	77.04
θ	0	75	32.18
v_{sl}	2.0	5.0	2.69
v_{sg}	0.2	33.86	13.55
Dp	0.05	0.70	0.33

Vsg (ft/sec)	ROP (ft/hr)	RPM	Vsl (ft/src)	Theta	Dp (psi/ft)
32.0475	80	80	3	12.5	0.35482
2.30769	120	120	2	45	0.33870
24.6450	100	0	3	12.5	0.35061
2.04651	100	80	3	12.5	0.70321
0.84158	80	120	2	70	0.33175

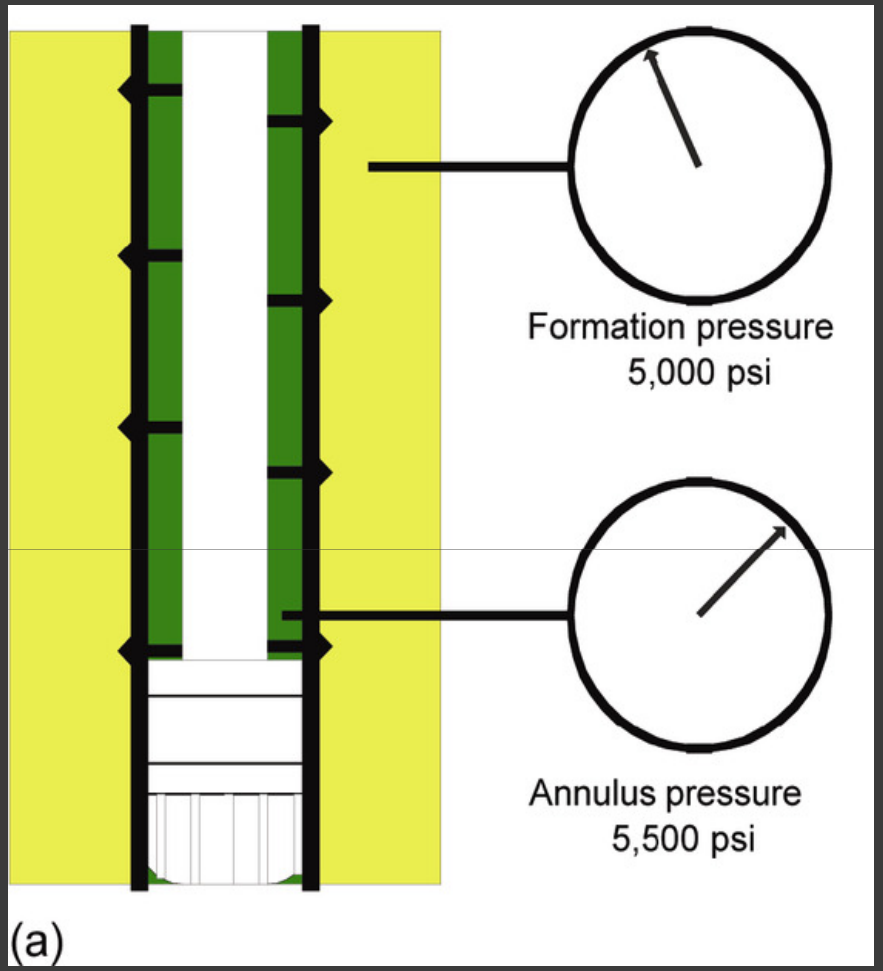
* Innovation & Novelty

The ecumenical inclination toward precision & optimization leads drilling procedures to be more innovative and unconventional. Accurate prediction and modeling are two of the most vital requirements in this new approach. Every unfortunate and unplanned incident should be ,firstly, predicted and then avoided. Every action should be precisely taken in total steps from drilling to production. Pressure plays a pivotal role in determining drilling approach.

* Drilling methods

* OBD

Overbalanced drilling, or OBD, is a procedure used to drill oil and gas wells where the pressure in the wellbore is kept higher than the fluid pressure in the formation being drilled. As the well is being drilled, wellbore fluid flows into the formation. However, excessive overbalance can dramatically slow the drilling process by effectively strengthening the near-wellbore rock and limiting removal of drilled cuttings under the bit. In addition, high overbalance pressures coupled with poor mud properties can cause differential sticking problems


Formation pressure
5,000 psi
Annulus pressure
5,500 psi
(a)

* OBD disadvantages

-Differential sticking

High overbalance pressures coupled with poor mud properties can cause differential sticking problems. A condition whereby the drillstring cannot be moved (rotated or reciprocated) along the axis of the wellbore. Differential sticking typically occurs when high-contact forces caused by low reservoir pressures, high wellbore pressures, or both, are exerted over a sufficiently large area of the drill string. Differential sticking is, for most drilling organizations, the greatest drilling problem worldwide in terms of time and financial cost.

-External Drilling Mud Solids Invasion

The invasion of artificial mud solids (weighting agents, fluid loss agents or bridging agents),or naturally generated mud solids produced by bit-rock interactions and not removed by surface solids control equipment into the formation during overbalanced drilling.

-Phase Trapping

The loss of both water or oil based drilling mud filtrate to the formation in the near wellbore region due to leak off during overbalanced drilling operations, can result in permanent entrapment of a portion or all of the invading fluid resulting in adverse relative permeability effects which can reduce oil or gas permeability in the near wellbore region5.

- Chemical Incompatibility of Invading Fluids with the In-situ Rock Matrix.

- Fluid-Fluid Incompatibility Effects Between Invading Fluids and In-Situ Fluids.

- Near Wellbore Wettability Alteration and Surface Adsorption Effects.

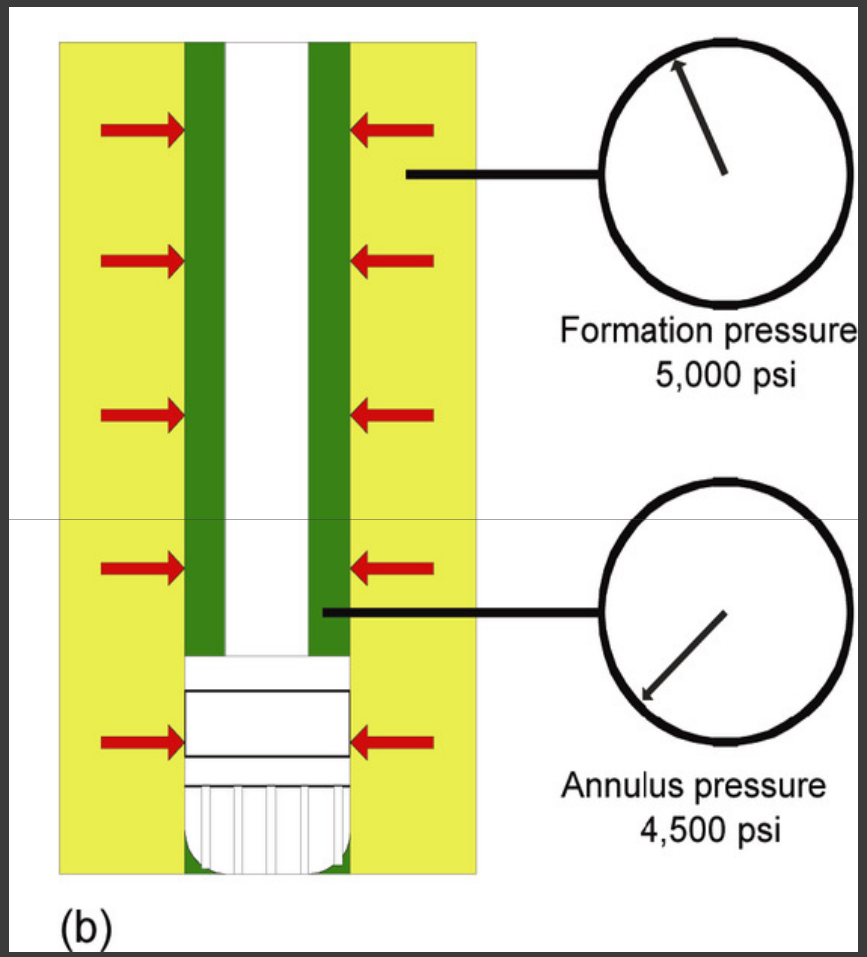
- Mechanical Near Wellbore Damage Effects.

- Fines Migration.

* UBD

Underbalanced drilling, or UBD, is a procedure used to drill oil and gas wells where the pressure in the wellbore is kept lower than the fluid pressure in the formation being drilled. As the well is being drilled, formation fluid flows into the wellbore and up to the surface. In such a conventional "overbalanced" well, the invasion of fluid is considered a kick, and if the well is not shut-in it can lead to a blowout, a dangerous situation. In underbalanced drilling, however, there is a "rotating head" at the surface - essentially a seal that diverts produced fluids to a separator while allowing the drill string to continue rotating.

How pressure is set in UBD If the formation pressure is relatively high, using a lower density mud will reduce the well bore pressure below the pore pressure of the formation. Sometimes an inert gas is injected into the drilling mud to reduce its equivalent density and hence its hydrostatic pressure throughout the well depth. This gas is commonly nitrogen, as it is non-combustible and readily available, but air, reduced oxygen air, processed flue gas and natural gas have all been used in this fashion.


Formation pressure
5,000 psi
Annulus pressure
4,500 psi
(b)

* Advantages of UBD

- Eliminated formation damage. In a conventional well, drilling mud is forced into the formation in a process called invasion, which frequently causes formation damage - a decrease in the ability of the formation to transmit oil into the wellbore at a given pressure and flow rate. It may or may not be repairable. In underbalanced drilling, if the underbalanced state is maintained until the well becomes productive, invasion does not occur and formation damage can be completely avoided.

- Increased Rate of Penetration (ROP. With less pressure at the bottom of the wellbore, it is easier for the drill bit to cut and remove rock.

- Reduction of lost circulation. Lost circulation is when drilling mud flows into the formation uncontrollably. Large amounts of mud can be lost before a proper mud cake forms, or the loss can continue indefinitely. If the well is drilled underbalanced, mud will not enter the formation and the problem can be avoided.

- Differential sticking is eliminated. Differential sticking is when the drill pipe is pressed against the wellbore wall so that part of its circumference will see only reservoir pressure, while the rest will continue to be pushed by wellbore pressure. As a result the pipe becomes stuck to the wall, and can require thousands of pounds of force to remove, which may prove impossible. Because the reservoir pressure is greater than the wellbore pressure in UBD, the pipe is pushed away from the walls, eliminating differential sticking.

- Prevention of reduced permeability, Formation damage Some rock formation have a reactive tendency to water. When drill mud is used the water in the drill mud reacts with the formation (mostly clay) and inheriently causes a formation damage (reduction in permeability and porosity) Use of underbalanced drilling can prevent it

* Pressure as a key factor

The functionality of UBD and MPD highly depends on pressure should be set in wellbore. Fluctuations in pressure profile of the wellbore can initiate difficulties and failures. By too low set pressure, it is not always possible to maintain a continuously underbalanced condition and, since there is no filter cake in the wellbore, any period of overbalance might cause severe damage to the unprotected formation. Moreover, it is not economical to put unnecessary excessive pressure which can cause many flaws.

* Drilling fluids utilizing in UBD method

-Dry air

-Mist

-Foam

-Stable foam

-Airlift

-Aerated mud

* Fractional Pressure loss

The pivotal role of pressure has been expatiated. So, any factors affecting the pressure should be recognized and consider in any calculation. Comprehensive understanding of well condition will be obtained by pressure modeling. One of the most important elements in determining reliable pressure profile is calculation of Frictional Pressure Loss. Each variable (flow rate of each phase, rate of penetration (ROP), pipe rotation, and hole inclination) , individually, causes pressure drop.

Modeling

* What is modeling?

Modeling is the process of producing a model; a mode is a representation of the construction and working of some system of interest. One purpose of a model is to enable the analyst to predict the effect of changes to the system. A good model is a judicious tradeoff between realism and simplicity.

* Types of modeling

The common trend for modeling is mathematical modeling which engages many complex formulas and equations. This approach has significant disadvantages including: uncertainty, errors and limitations. For example, In PVTi simulation software, there is too many formulas and structures need to be tested then applied in order to get to a acceptable model (with less possible errors). As it's been stated before, the ecumenical inclination is toward precision. It means no more uncertainty can be accepted in any approaches. Consequently, the need of a pervasive modeling approach leads scientist to think of a new way.

* Support vector machines

Artificial intelligence (AI) is the intelligence exhibited by machines or software. Major AI researchers and textbooks define this field as "the study and design of intelligent agents", where an intelligent agent is a system that perceives its environment and takes actions that maximize its chances of success. The central goals of AI research include reasoning, knowledge, planning, learning, natural language processing (communication), perception and the ability to move and manipulate objects.

Machine learning is a subfield of computer science and statistics that deals with the construction and study of systems that can learn from data, rather than follow only explicitly programmed instructions. Besides CS and Statistics, it has strong ties to artificial intelligence and optimization, which deliver both methods and theory to the field. Machine learning is employed in a range of computing tasks where designing and programming explicit, rule-based algorithms is infeasible. Machine learning tasks can be of several forms.

Supervised learning is the machine learning task of inferring a function from labeled training data. The training data consist of a set of *training examples*. In supervised learning, each example is a *pair* consisting of an input object (typically a vector) and a desired output value (also called the *supervisory signal*). A supervised learning algorithm analyzes the training data and produces an inferred function, which can be used for mapping new examples. An optimal scenario will allow for the algorithm to correctly determine the class labels for unseen instances. This requires the learning algorithm to generalize from the training data to unseen situations in a "reasonable" way.

regression analysis is a statistical process for estimating the relationships among variables. It includes many techniques for modeling and analyzing several variables, when the focus is on the relationship between a dependent variable and one or more independent variables. while the other independent variables are held fixed. Regression analysis is widely used for prediction and forecasting, where its use has substantial overlap with the field of machine learning

support vector machines (**SVMs**, also **support vector networks**) are supervised learning models with associated learning algorithms In machine learning that analyze data and recognize patterns, used for classification and regression analysis. The original SVM algorithm was invented by Vladimir N. Vapnik.

Teaching & Learning

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
1	Train									Validation									Test						
2	Vsg (ft/se	ROP (ft/hr)	RPM	Vsl (ft/src)	theta	Dp (psi/ft)	Dp (psi/ft)	Predicted by model		Vsg (ft/se	ROP (ft/hr	RPM	Vsl (ft/src	theta	Dp (psi/ft)	Dp (psi/ft)	Predicted by model		Vsg (ft/se	ROP (ft/hr	RPM	Vsl (ft/src	theta	Dp (psi/ft)	Dp (psi/ft
3	20.8725	80	80	2	45	0.26007	0.2617			13.9791	120	120	2	0	0.05	0.05232			1.91568	120	0	3	12.5	0.55746	0.50506
4	2.60243	80	80	2	45	0.41611	0.41225			7.22307	100	80	2	45	0.32383	0.32153			18.8527	120	80	3	12.5	0.4484	0.43023
5	13.4653	80	120	2	70	0.19975	0.1907			16.5379	80	80	5	45	0.39011	0.43242			11.1386	80	80	2	70	0.17575	0.1863
6	30.8574	80	80	2	45	0.2802	0.27729			13.7666	120	0	2	45	0.23644	0.2375			17.8647	120	0	2	45	0.23418	0.25422
7	4.5092	80	0	3	12.5	0.45228	0.45711			27.592	80	100	3	12.5	0.36244	0.37214			12.4294	80	80	4	45	0.34066	0.36123
8	4.77997	100	80	2	45	0.36242	0.367			7.13178	120	80	3	12.5	0.54321	0.55554			22.2016	100	80	3	12.5	0.41086	0.40273
9	14.6572	120	120	2	12.5	0.33594	0.33773			3.88314	120	0	3	12.5	0.50098	0.48415			4.96124	120	80	3	12.5	0.58272	0.58537
10	6.18871	80	80	5	45	0.38736	0.41847			17.6234	80	80	5	12.5	0.52973	0.53512			1.08911	80	80	2	70	0.3085	0.31437
11	11.273	80	100	3	12.5	0.44619	0.4436			18.5888	100	80	2	45	0.25671	0.27748			8.12403	100	80	3	12.5	0.52148	0.51434
12	20.2385	120	120	2	12.5	0.30781	0.3035			30.099	80	0	2	70	0.14125	0.10039			9.91058	120	120	2	12.5	0.37031	0.39743
13	29.0849	120	80	2	45	0.24605	0.24672			4.85411	120	120	2	45	0.29068	0.30139			2.49621	100	80	2	45	0.40604	0.4262
14	0.36513	120	120	2	0	0.07344	0.07598			10.1714	120	120	2	60	0.19219	0.16541			23.7519	120	80	3	12.5	0.42667	0.41303
15	19.6062	80	80	4	45	0.36539	0.36685			25.0282	80	80	5	12.5	0.52658	0.50503			25.924	120	120	2	75	0.13438	0.13474
16	0.95599	100	80	2	45	0.47819	0.4752			4.05941	80	80	2	70	0.2665	0.26342			0.84158	80	120	2	70	0.33175	0.35594
17	9.65347	80	120	2	70	0.202	0.20038			2.89877	80	80	3	12.5	0.58173	0.50898			5.95349	100	80	3	12.5	0.55111	0.53736
18	33.8605	100	80	3	12.5	0.39704	0.39712			16.1021	120	0	3	12.5	0.37188	0.37545			2.07101	120	0	3	12.5	0.53032	0.50342
19	9.35013	120	0	2	45	0.2404	0.24227			7.45562	100	0	3	12.5	0.44963	0.45629			2.91473	100	80	3	12.5	0.62617	0.56909
20	4.35644	80	120	2	70	0.28	0.26397			5.42474	120	120	2	12.5	0.475	0.4853			8.789	80	80	4	45	0.36126	0.3645
21	9.28068	80	80	5	12.5	0.55496	0.55316			27.6975	120	120	2	0	0.06094	0.05802			20.5446	80	0	2	70	0.1345	0.15628
22	19.5358	120	80	2	45	0.26186	0.25937			29.8408	120	120	2	45	0.26243	0.24864			13.8119	80	80	2	70	0.19	0.17453
23	19.7009	80	0	3	12.5	0.34949	0.34797			24.8286	120	120	2	0	0.05938	0.05734			6.31657	120	0	3	12.5	0.45403	0.4585
24	15.5083	100	80	2	45	0.27349	0.27503			22.8465	120	120	2	0	0.05156	0.05632			26.1406	120	80	2	45	0.22627	0.25794
25	11.1008	100	80	3	12.5	0.48395	0.48371			0.44555	80	80	2	70	0.34675	0.32654			2.04651	120	80	3	12.5	0.70321	0.62471
26	17.8209	80	80	4	12.5	0.44775	0.45845			24.0903	80	80	4	12.5	0.42252	0.44213			29.158	120	120	2	75	0.19063	0.13126
27	30.5446	80	80	2	70	0.199	0.18575			24.3069	80	120	2	70	0.18025	0.19092			19.5192	100	0	3	12.5	0.36235	0.37568
28	32.1287	80	120	2	70	0.18925	0.18567			21.1273	120	0	2	45	0.20141	0.27884			12.6895	80	80	5	45	0.38599	0.42036
29	18.152	120	120	2	75	0.15469	0.15456			18.8979	120	0	3	12.5	0.35721	0.362			11.8047	120	0	3	12.5	0.39389	0.40617
30	2.95245	80	100	3	12.5	0.58249	0.57581			13.796	80	100	3	12.5	0.43401	0.42478			5.26074	80	80	3	12.5	0.51091	0.48695
31	8.58098	80	80	5	45	0.4272	0.41383			22.0092	80	100	3	12.5	0.36929	0.39425			15.6366	120	120	2	45	0.27147	0.25581
32	22.1545	80	80	5	45	0.43956	0.43986			19.1089	80	120	2	70	0.1885	0.19371			12.093	120	80	3	12.5	0.50173	0.49161
33	9.82549	100	80	2	45	0.29362	0.29183			2.19076	120	120	2	75	0.24688	0.22743			8.18927	120	120	2	75	0.1875	0.19563
34	1.82563	120	120	2	0	0.07031	0.07161			23.6107	80	80	4	45	0.39835	0.36254			16.6411	80	80	3	12.5	0.40279	0.40917

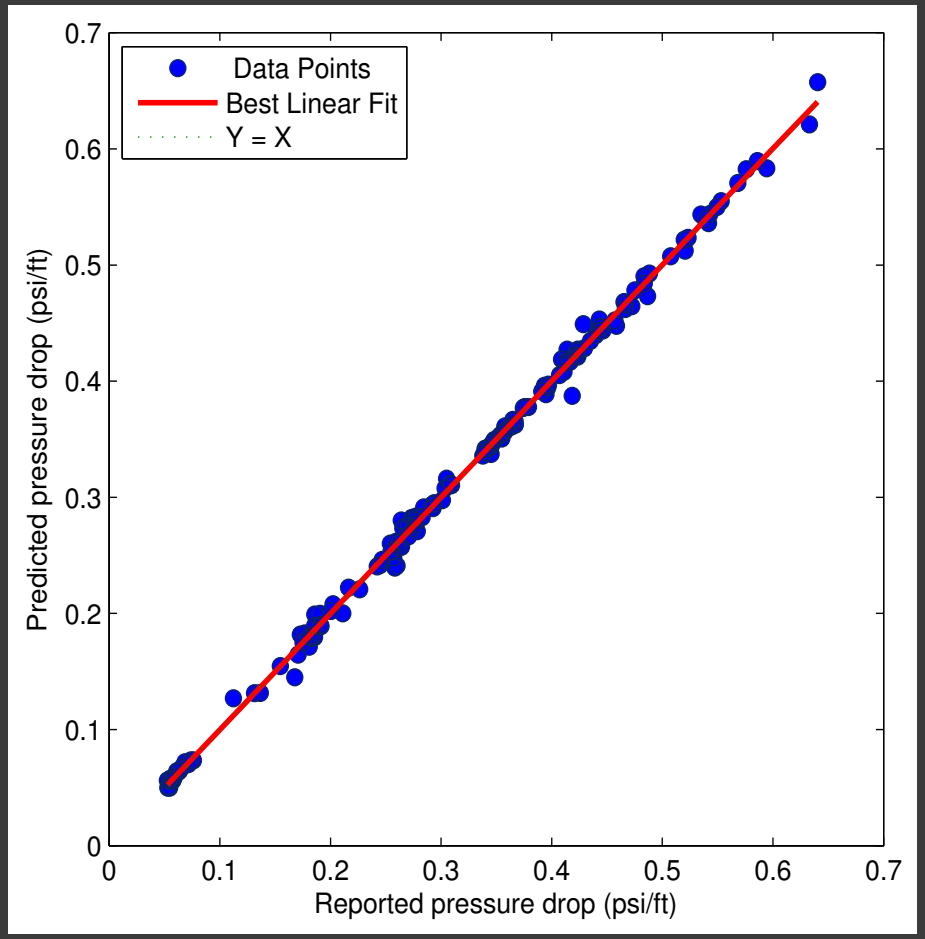
* Training

As we talked before, this network is capable of learning from data, rather than follow only explicitly programmed instructions. For better understanding of the network, I will explain it by an example.

* The class

1-Memorizing,

2*2=4 ➔ 2*3=4



As you can see, the predicted frictional pressure losses are almost equal to the experimental ones, correlation coefficient (R^2)= 0.997

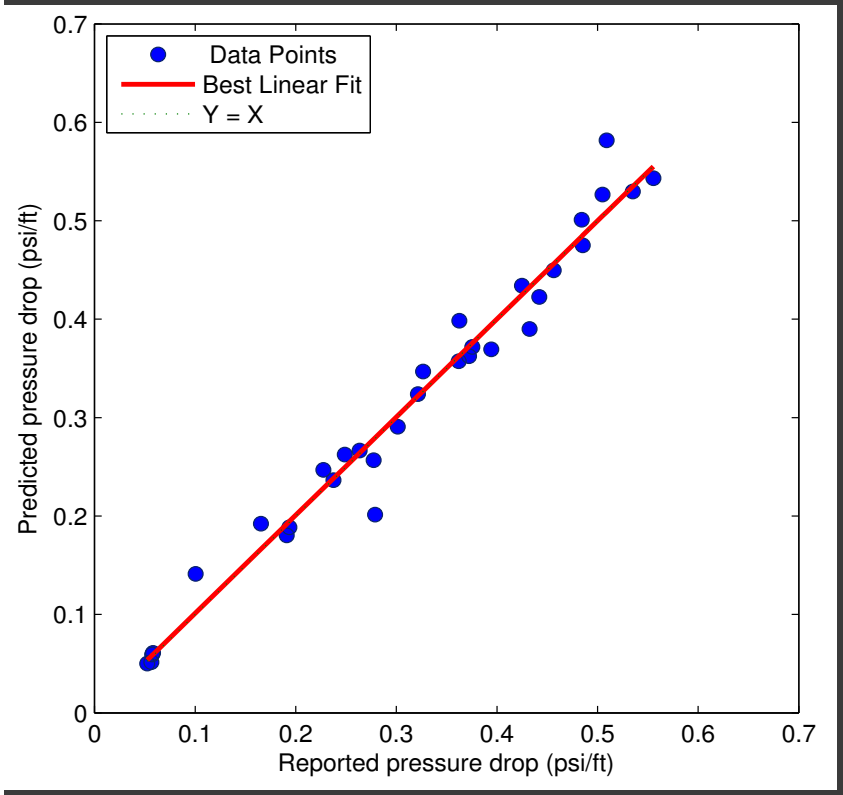
* Validating and Testing

* The class

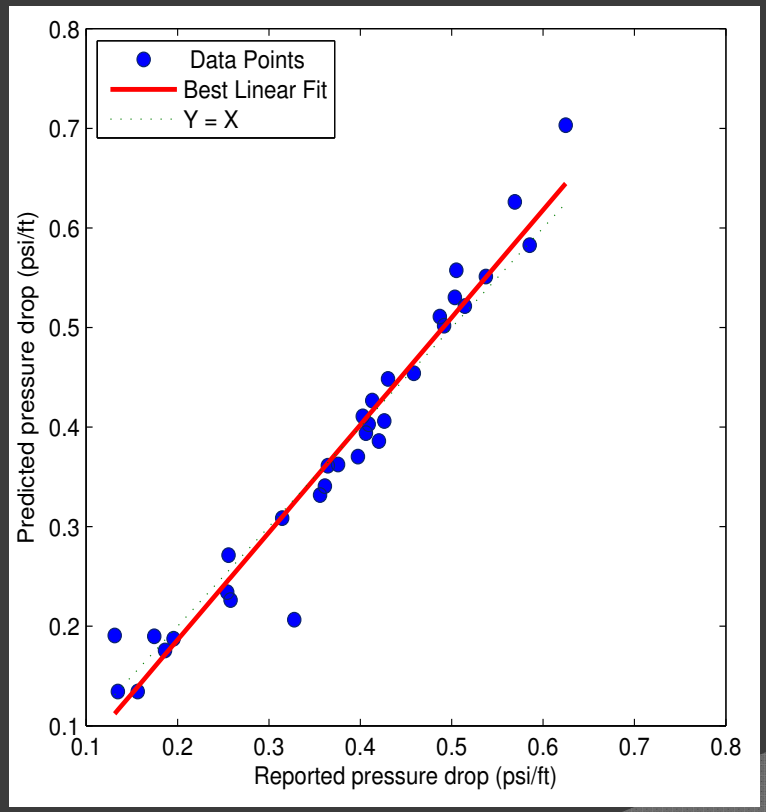
2- Realization & algorithm production

2*2=4 ➔ 2*5=10

Validation

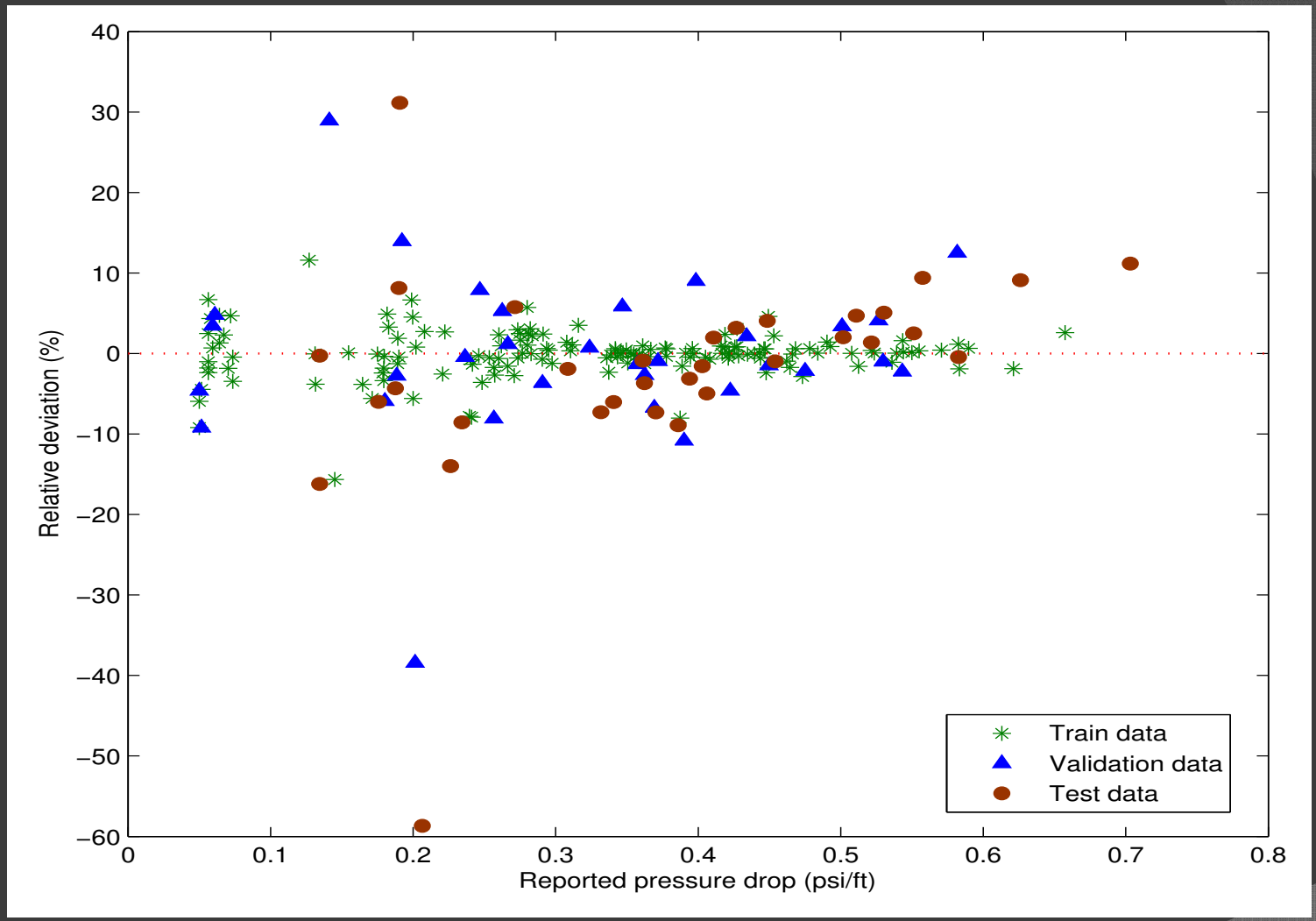


Test

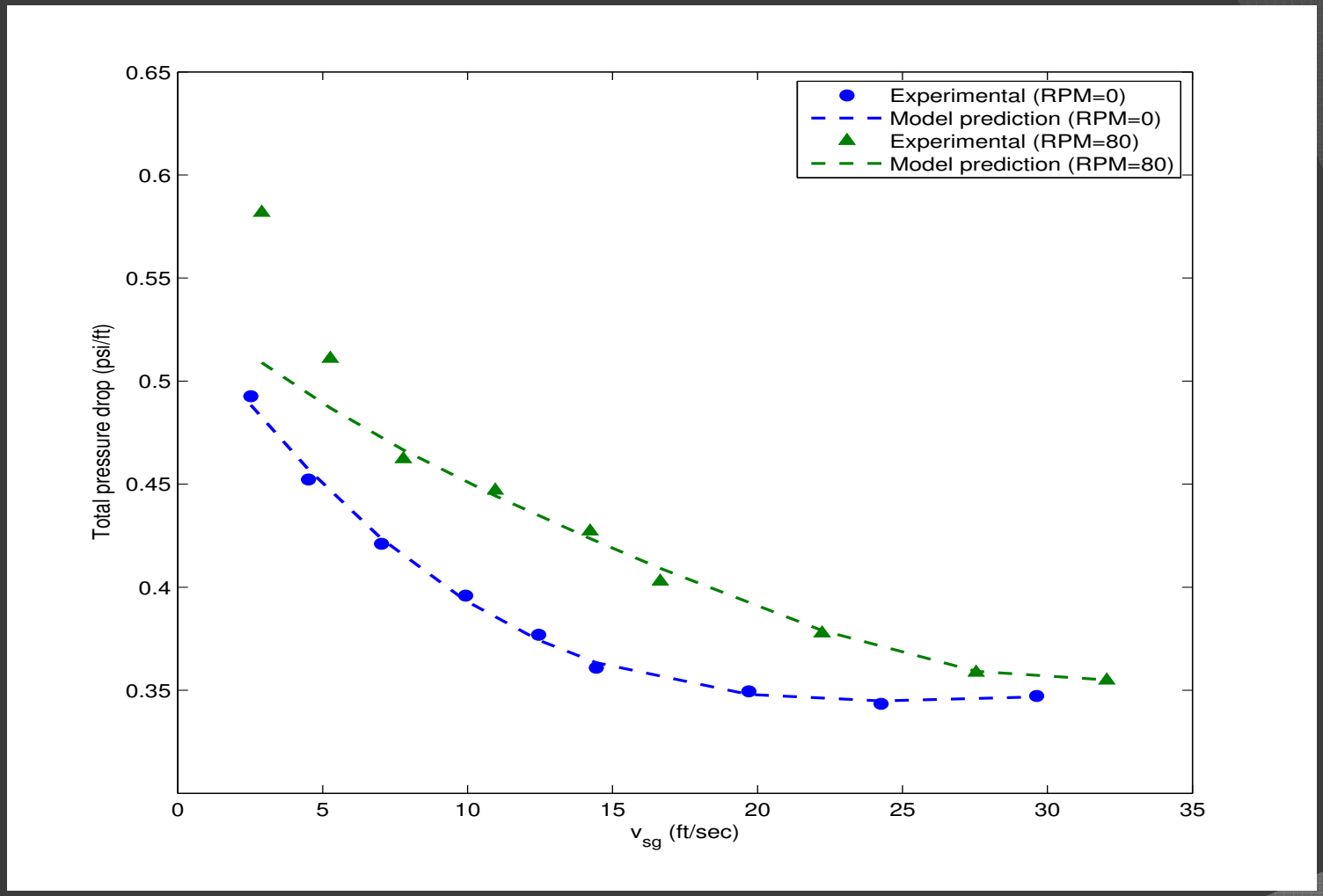


A tight cloud of points about 45° line for training, validation and testing data sets indicate the robustness of the proposed models. In addition

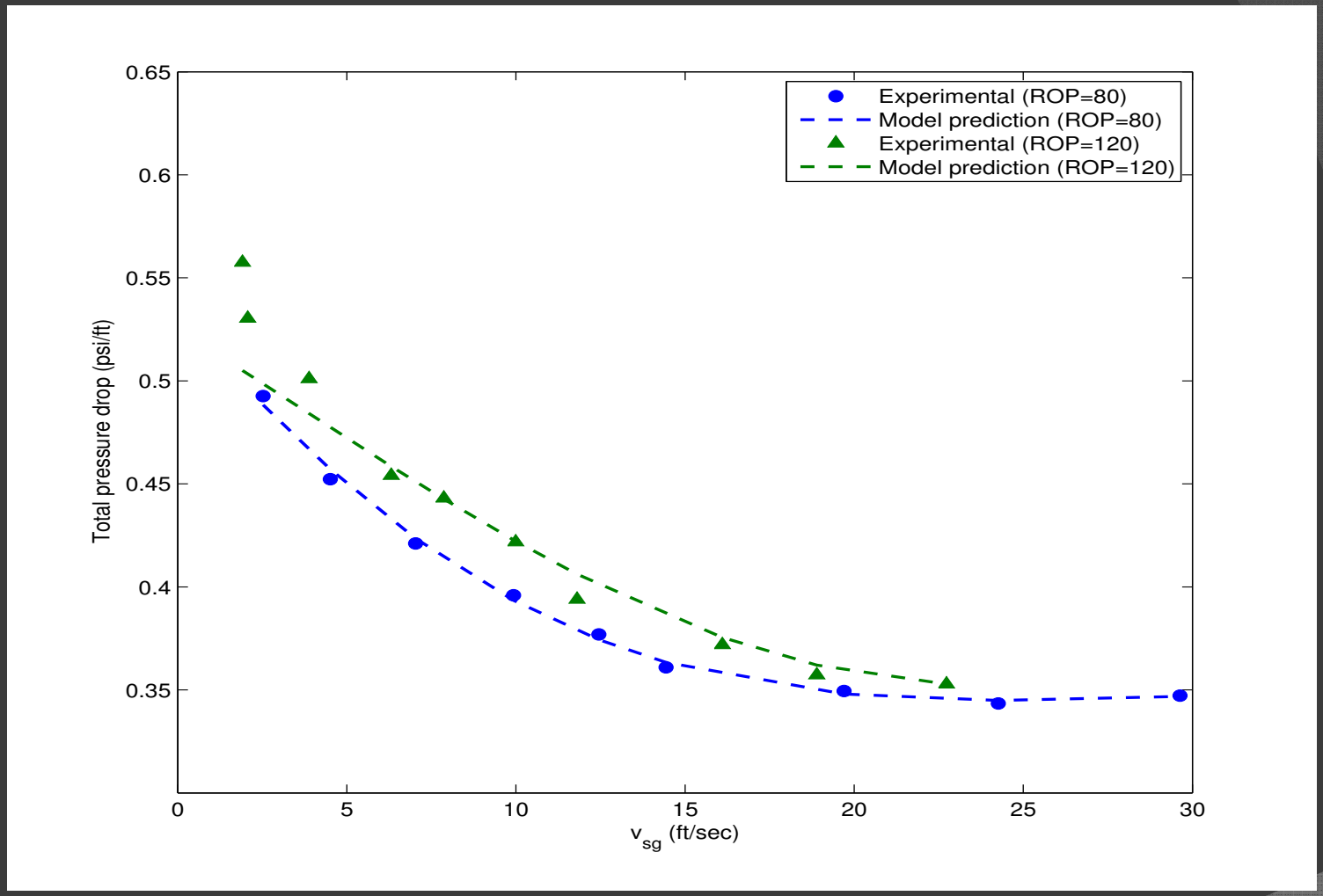
Trend analysis



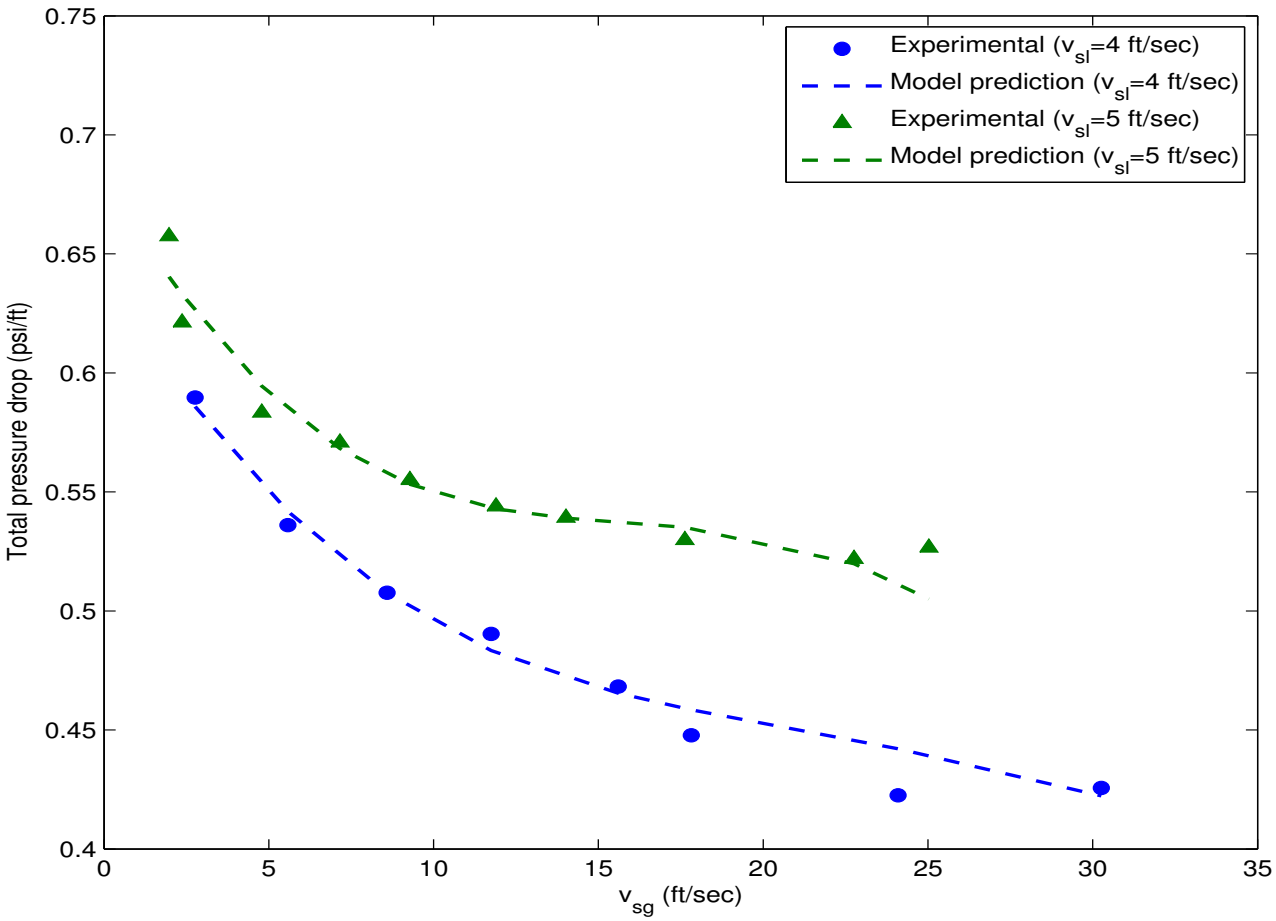
for representing a better visual comparison, Relative deviations of estimated values are plotted versus the target (reported) data in the fig for all data. As illustrated, predictions are in a satisfactory agreement with the reported data.



Measured and predicted pressure drop versus gas superficial velocity (*Θ=12.5, ROP=80 ft/hr,)*



Measured and predicted pressure drop versus gas superficial velocity (*Θ=12.5, RPM=0ft/hr,)*



Measured and predicted pressure drop versus gas superficial velocity (Θ=12.5, RPM=80ft/hr, ROP=80(ft/hr))

Table

Table 2: The statistical parameters of the developed model.

Parameter	
Training set	
R^2	0.9979
Average relative deviation, %	-0.092
Average absolute relative deviation, %	1.867
Root mean square error	0.007
N	151
Validation set	
R^2	0.9713
Average relative deviation, %	-0.138
Average absolute relative deviation, %	6.573
Root mean square error	0.025
N	32
Test set	
R^2	0.9514
Average relative deviation, %	-1.684
Average absolute relative deviation, %	7.721
Root mean square error	0.034
N	33
Total	
R^2	0.9862
Average relative deviation, %	-0.342
Average absolute relative deviation, %	3.459
Root mean square error	0.018
N	216

Average absolute relative error

$$AARD\% = \frac{100}{N}\sum_{i=1}^{N}\left(\left|\frac{Dp_i^{exp} - Dp_i^{pred}}{Dp_i^{exp}}\right|\right)$$

Average relative deviation

$$ARD\% = \frac{100}{N}\sum_{i=1}^{N}\left(\frac{Dp_i^{exp} - Dp_i^{pred}}{Dp_i^{exp}}\right)$$

Root mean square error (RMSE)

$$RMSE = \left(\frac{\sum_{i=1}^{N}\left(Dp_i^{exp} - Dp_i^{pred}\right)^2}{N}\right)^{\frac{1}{2}}$$