Expert Systems for Gas Production Prediction from Hydraulically Fractured Horizontal Wells based on Different Hydraulic Fracture Representations*

Nithiwat Siripatrachai[1], Kanin Bodipat[1], and Turgay Ertekin[1]

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[1]Pennsylvania State University (nxs298@psu.edu)

Abstract

To unlock natural gas from shale reservoirs, horizontal wells coupled with hydraulic fracturing are implemented. In this article, two hydraulic fracture representations (discrete transverse fracture representation and crushed zone representation) are considered. Service companies design multi-stage transverse hydraulic fracture treatments. In each stage, a massive volume of pressurized fluid is injected into the reservoir to create fractures which serve as high permeability pathways for natural gas to flow to the wellbore. In reservoir simulation studies, each fracture can be represented by a transverse fracture plane of high conductivity. However, microseismic field data show that multi-stage hydraulic fracturing can result in a stimulated reservoir volume which is referred as "crushed zone". The "crushed zone" has relatively higher permeability and smaller fracture spacing compared to the unstimulated zone. In the numerical model, crushed zone is represented by an elliptic zone of higher permeability and smaller fracture spacing around the wellbore.

Conducting simulation runs for optimization of a design can be time consuming and the optimal design may never be achieved. Additionally, we are interested in the equivalency of the two representations described above. In this study, the equivalency between the two hydraulic fracture representations is achieved when the average gas production rates from two representations are in agreement within a margin of ±10%. Establishing the equivalency between the two representations can prove to be an arduous task. In this work, artificial neural network (ANN) technology is utilized to make the sought equivalency more easily attainable. ANN is widely accepted for its ability to instantly provide simulation results for complex problems. Accordingly, a properly structured and trained ANN can serve as a powerful tool in reservoir simulation and overcome the aforementioned challenges. We use numerical reservoir models to generate production profiles for a hydraulically fractured horizontal well to train the network which eventually establishes the sought equivalency between two representations. The search process can start with any of the two hydraulic fracture representations. Given reservoir properties and one hydraulically fractured horizontal well modeled with one representation, the developed ANNs can instantly predict gas production rates as well as establish its equivalent hydraulic fracture representation.

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Turgay Ertekin

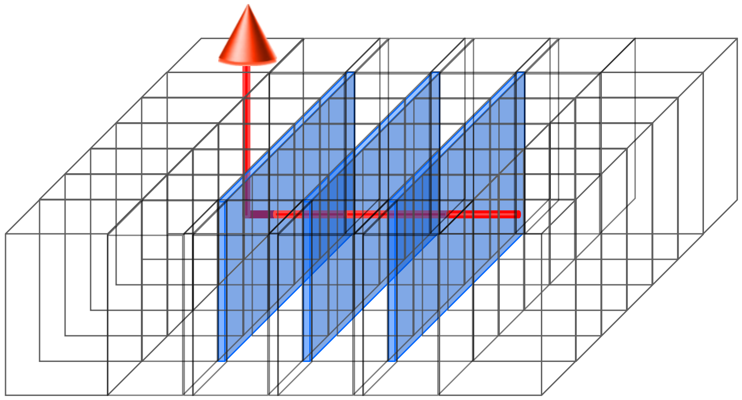
The Pennsylvania State University

Objectives

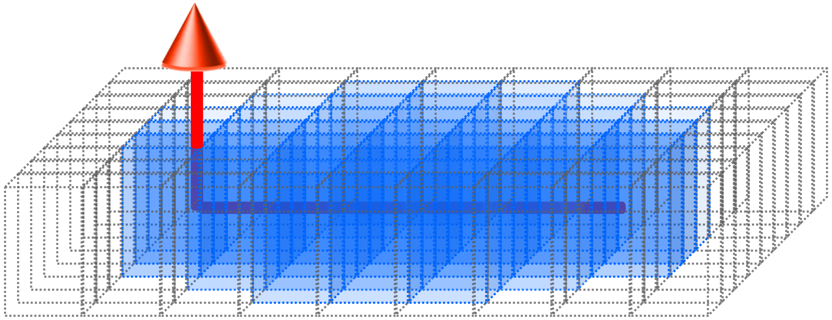
- Challenges in Shale Gas Development
  - Insufficient known or accurate reservoir parameters
  - Difficulty in characterization of hydraulic fracture
  - Time constraints in modeling efforts toward optimized field development
- Artificial Neural Networks can be used as tools to overcome some of these challenges.

Objectives

- Four ANNs have been developed:
  - Gas Production Prediction ANNs
    - Transverse hydraulic fracture representation
    - Crushed zone representation
  - Equivalency ANNs
    - Transverse-to-crushed zone ANN
    - Crushed zone-to-transverse ANN

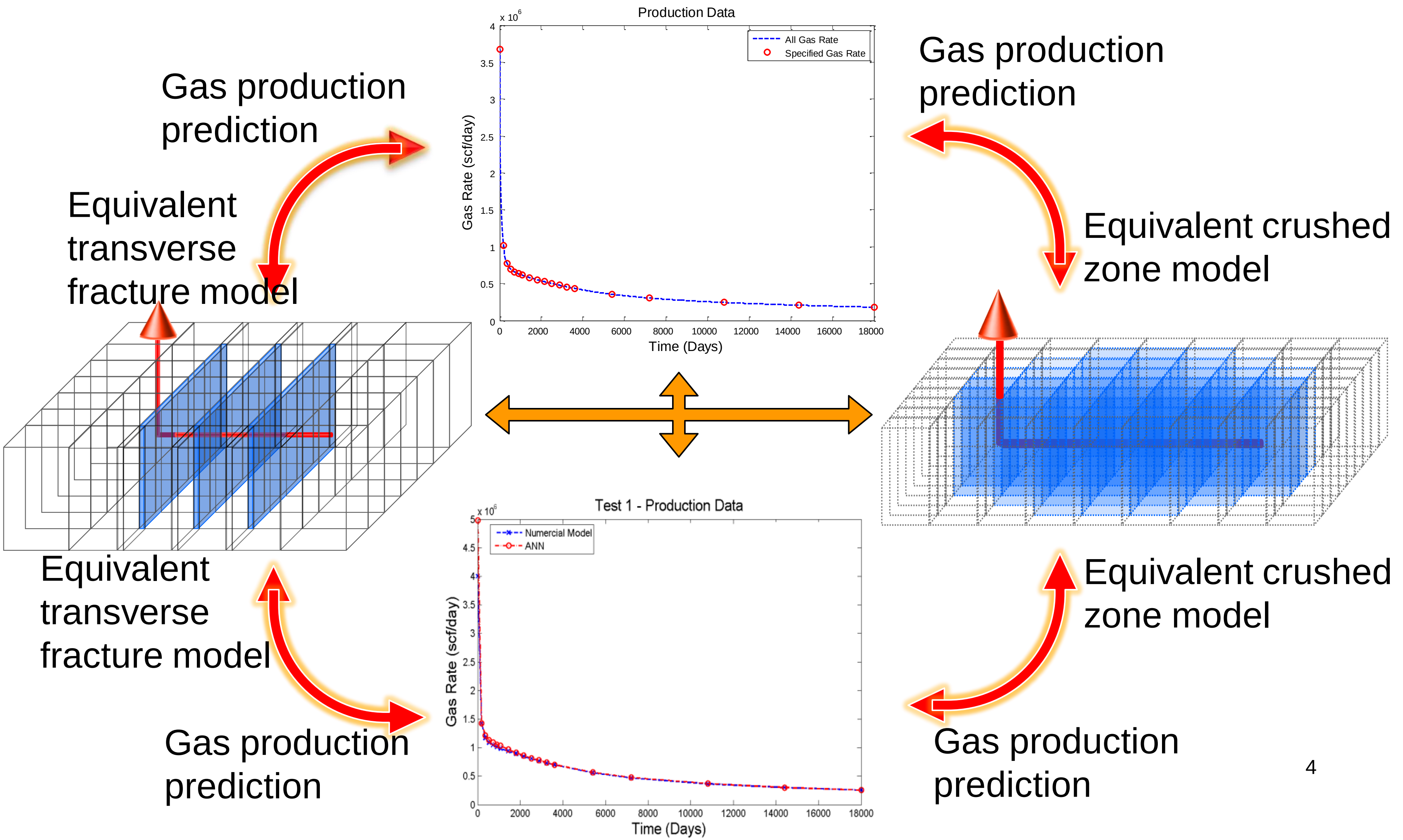


Transverse Fracture Model



Crushed Zone Model

Objectives

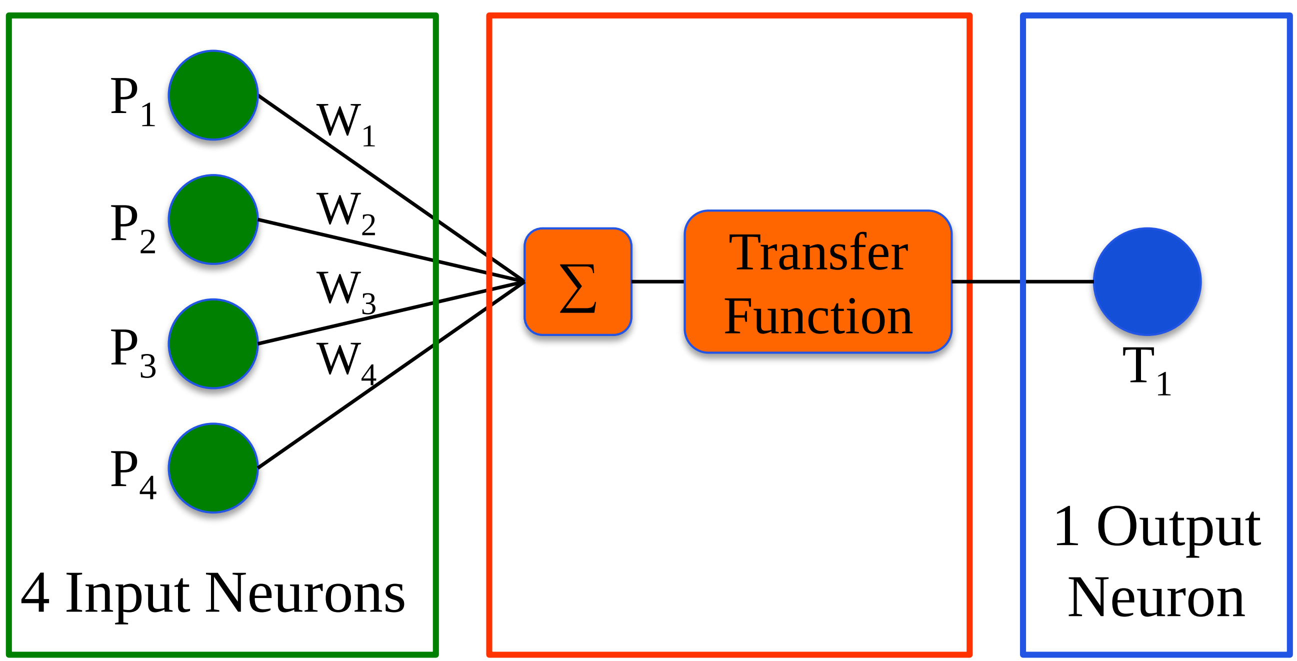

Gas production prediction
Equivalent transverse fracture model
Production Data
x 10^6
All Gas Rate
Specified Gas Rate
Gas Rate (scf/day)
Time (Days)
Gas production prediction
Equivalent crushed zone model
Equivalent transverse fracture model
Test 1 - Production Data
Numercial Model
ANN
Gas Rate (scf/day)
Time (Days)
Equivalent crushed zone model
Gas production prediction
Gas production prediction

Outline

- Background
- Generation of Training and Testing Sets
- Development of ANNs
- Results and Discussions
- Summary and Conclusions

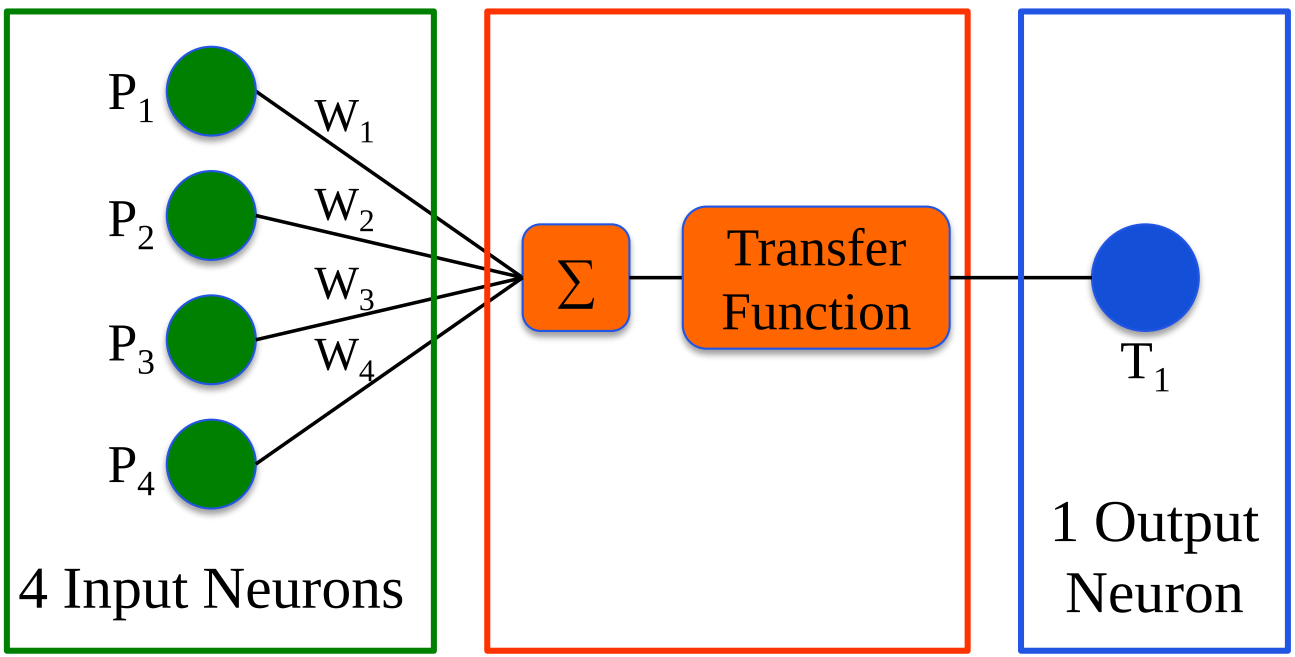
Background

- Artificial Neural Networks
  - Information-processing system
  - Ability to handle non-linear systems



Background

- Values of these weights are constantly modified during training
- Important inputs carry more weight



Background

- Training ANNs
  - Type of network
    - Cascade feed-forward backpropagation network
    - Feed-forward backpropagation network
  - Training & learning algorithm
  - Transfer functions
  - Number of hidden layers
  - Number of neurons in each layer
  - Functional links
  - Achieve generalization
  - Avoid memorization and local minima

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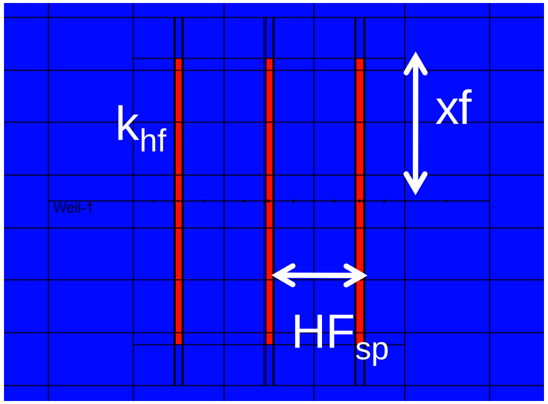
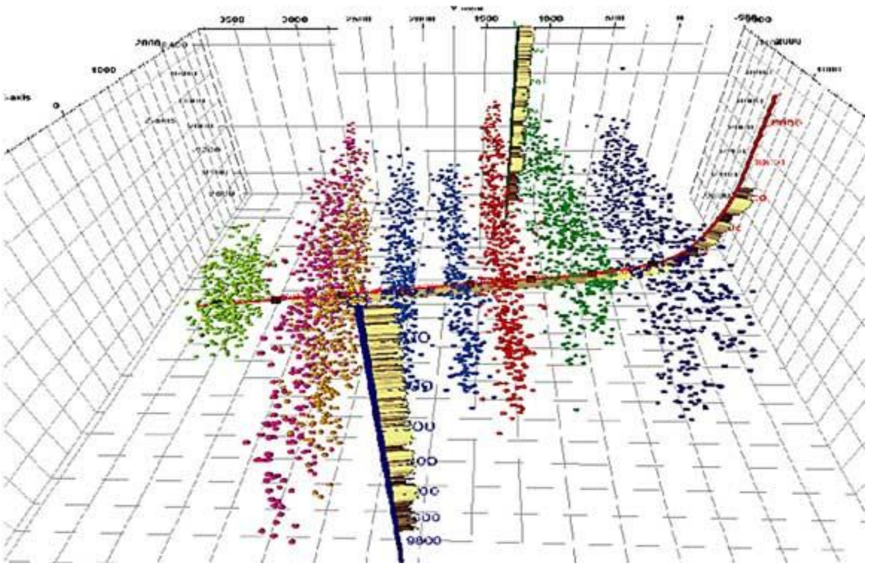
Generation of Training and Testing Sets

- Model Descriptions and Assumptions
  - 2-dimensional transport model
  - Homogeneous, isotropic square reservoir
  - Dual-porosity, dual-permeability system
  - Reservoir contains mainly methane and a negligibly small amount of residual water
  - One horizontal well is placed at the center of the reservoir
  - The well is produced at a constant specified pressure

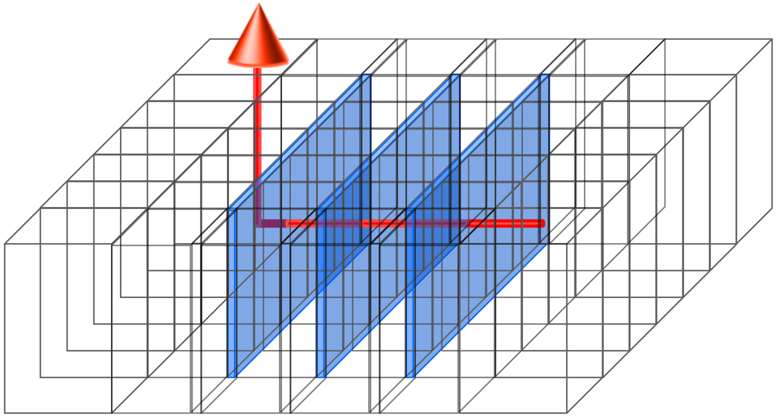
Generation of Training and Testing Sets

- Transverse Hydraulic Fracture Representation
  - Transverse planes of high permeability





Microseismic Field Data

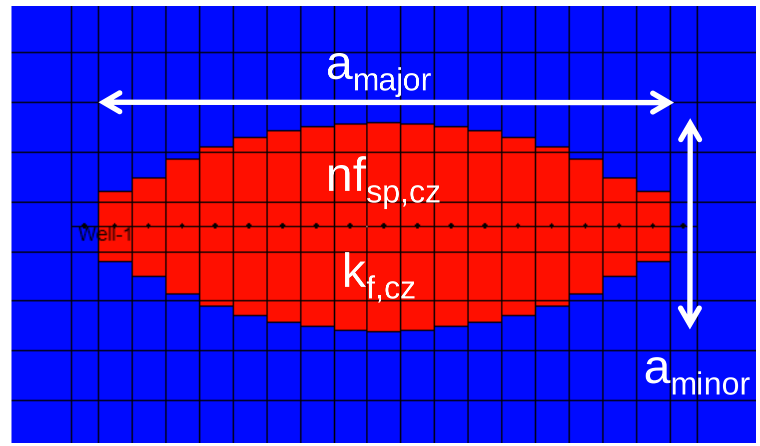


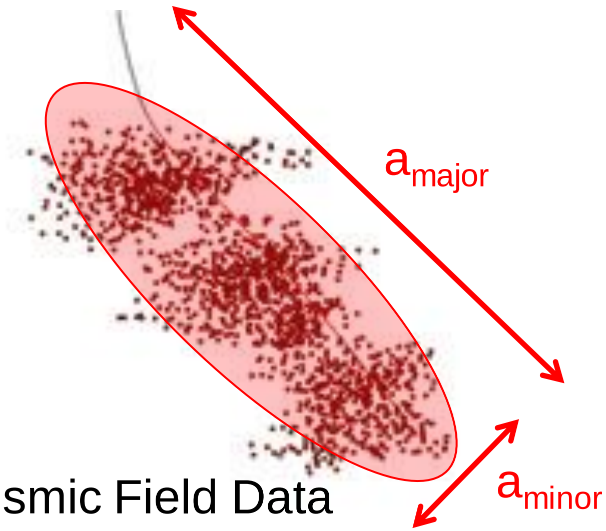
Transverse Fracture Planes

Source: National Energy Board (http://www.neb-one.gc.ca)

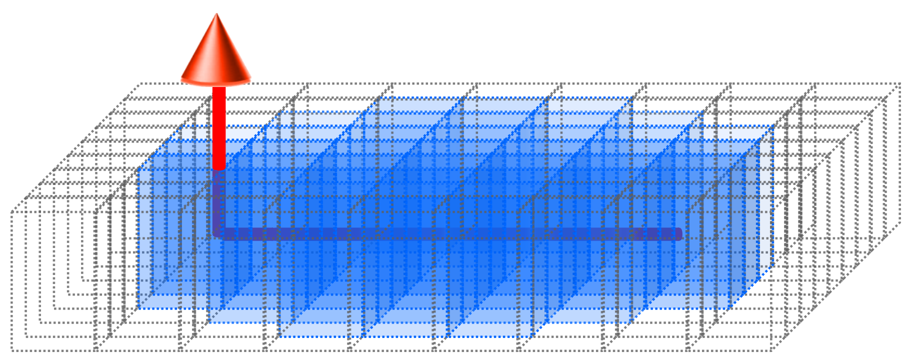
Generation of Training and Testing Sets

- Crushed Zone Hydraulic Fracture Representation
  - Elliptical zone of high permeability and smaller fracture spacing





Microseismic Field Data

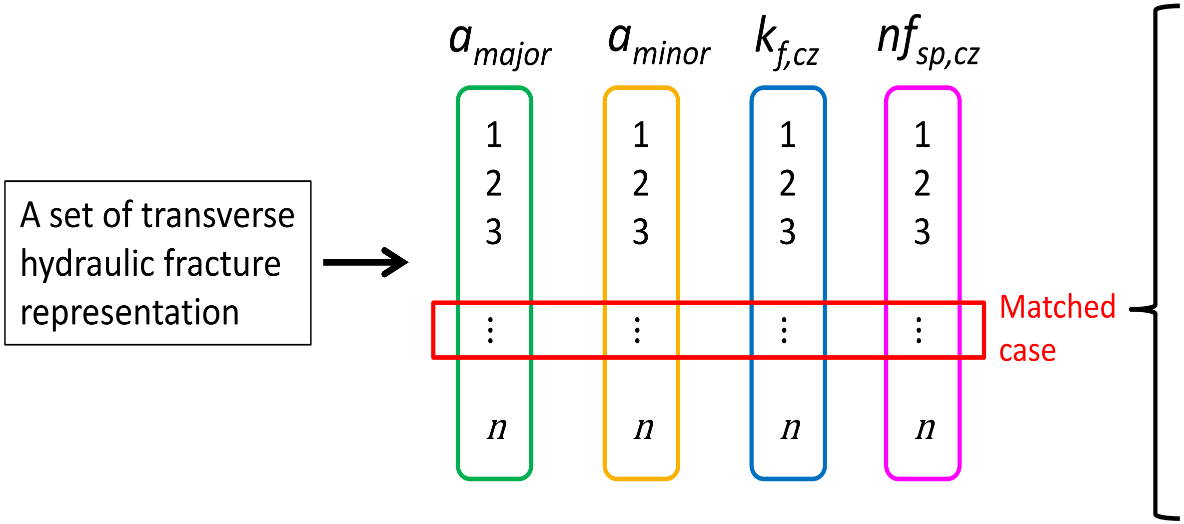


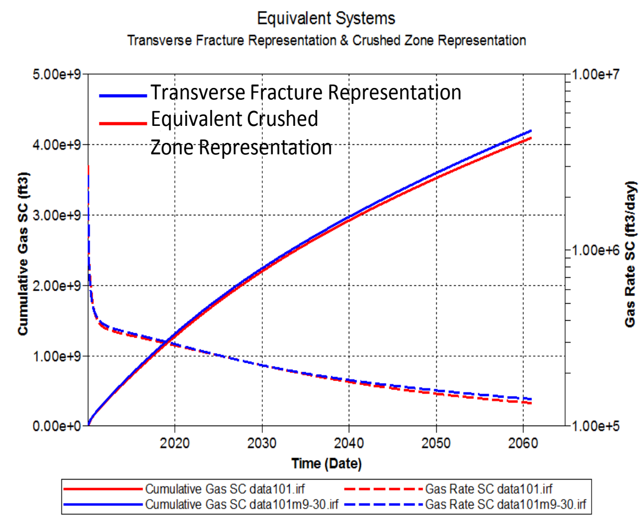
Crushed Zone

Source: Hart Energy Exploration and Production. (http://www.epmag.com)

Generation of Training and Testing Sets

- Establishing Equivalency
  - Matching Protocol

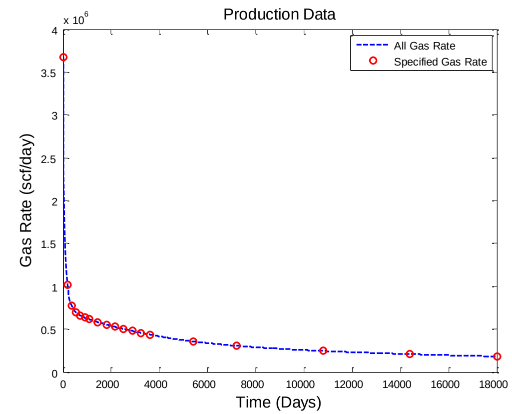


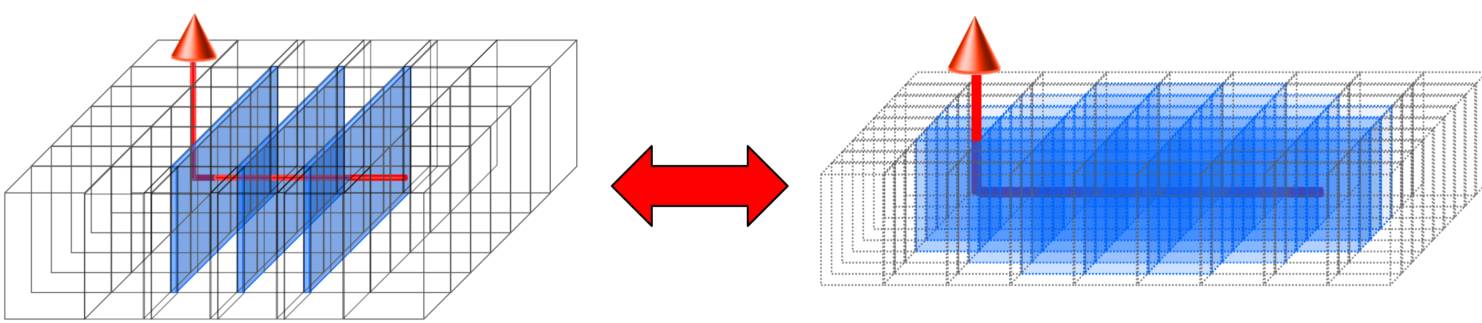


Matched case:
Cumulative production value agrees within ±10%

Generation of Training and Testing Sets

- Gas Production Prediction ANNs
  - Transverse Hydraulic Fracture Representation
  - Crushed Zone Representation
- Equivalency ANNs
  - Transverse to Crushed Zone
  - Crushed Zone to Transverse





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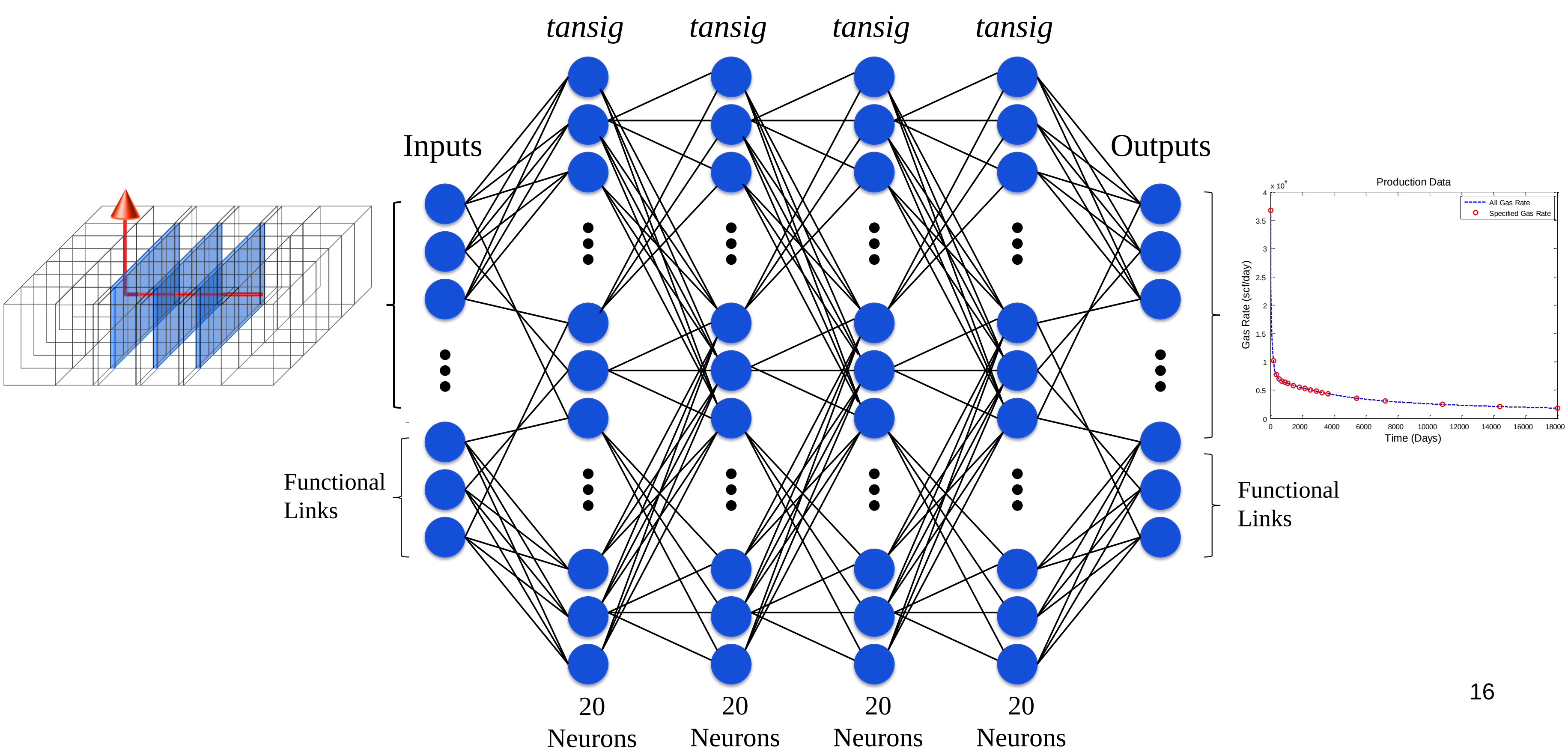
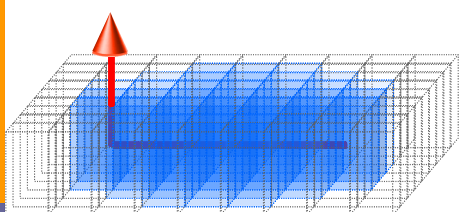
Development of ANNs

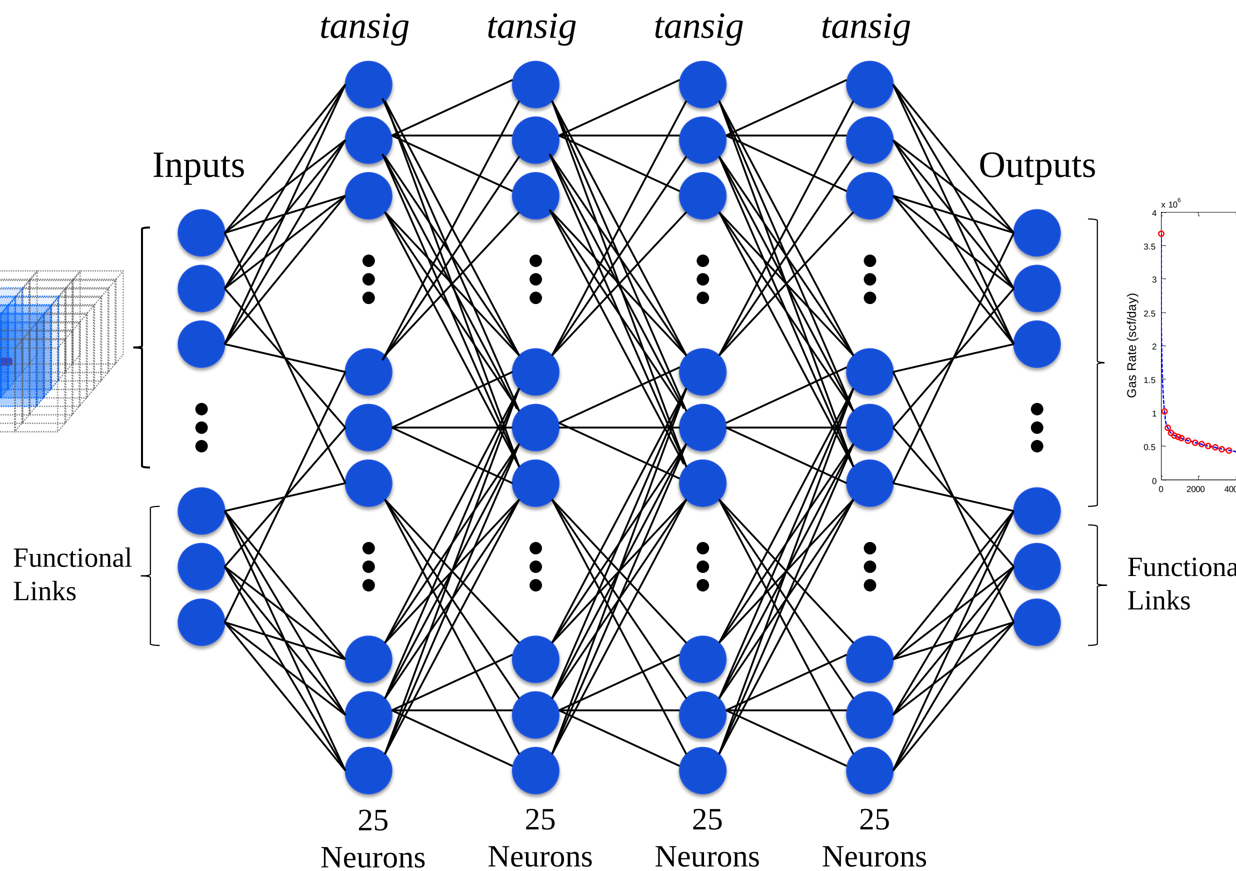
- Gas Production Prediction ANN
  - Transverse fracture representation

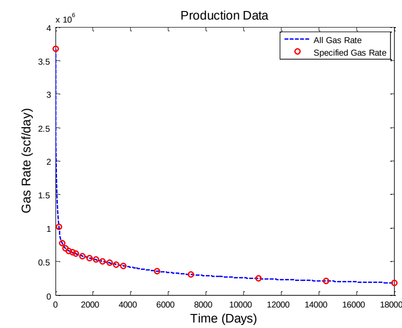


Development of ANNs

- Gas Production Prediction ANN
  - Crushed zone representation

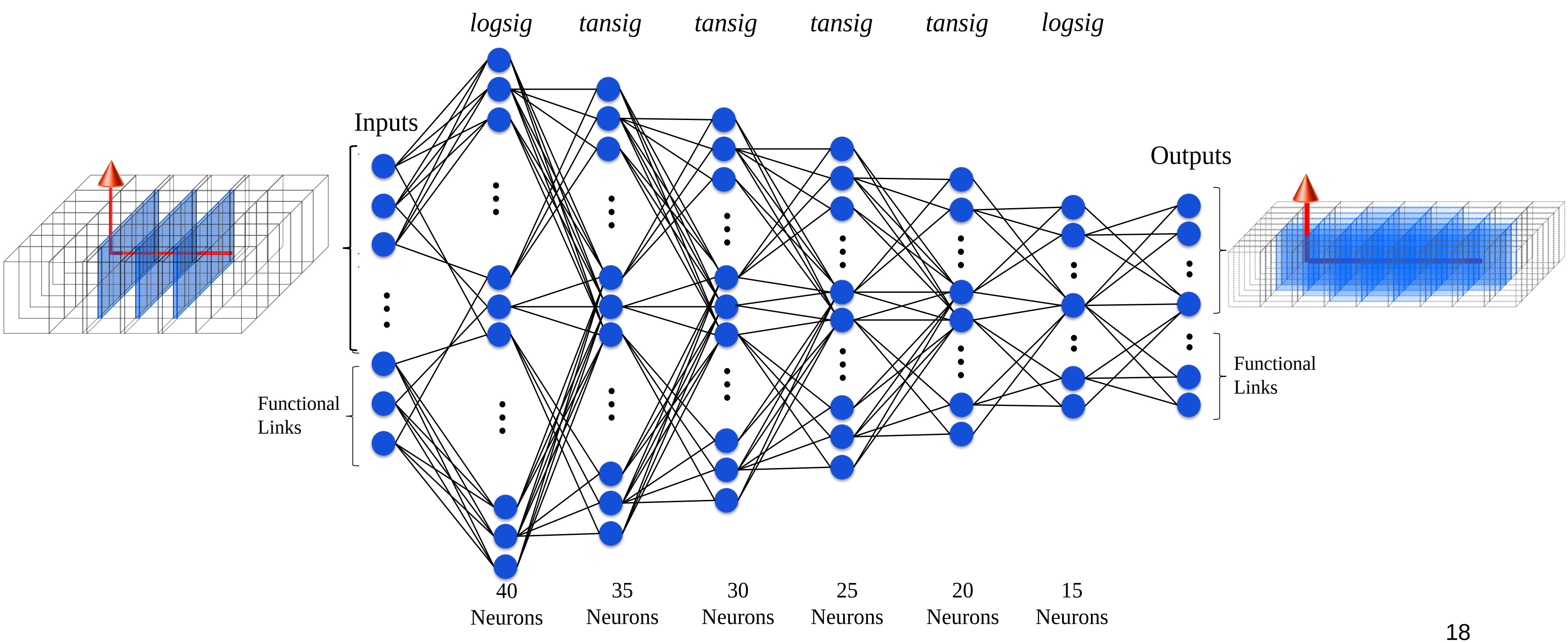






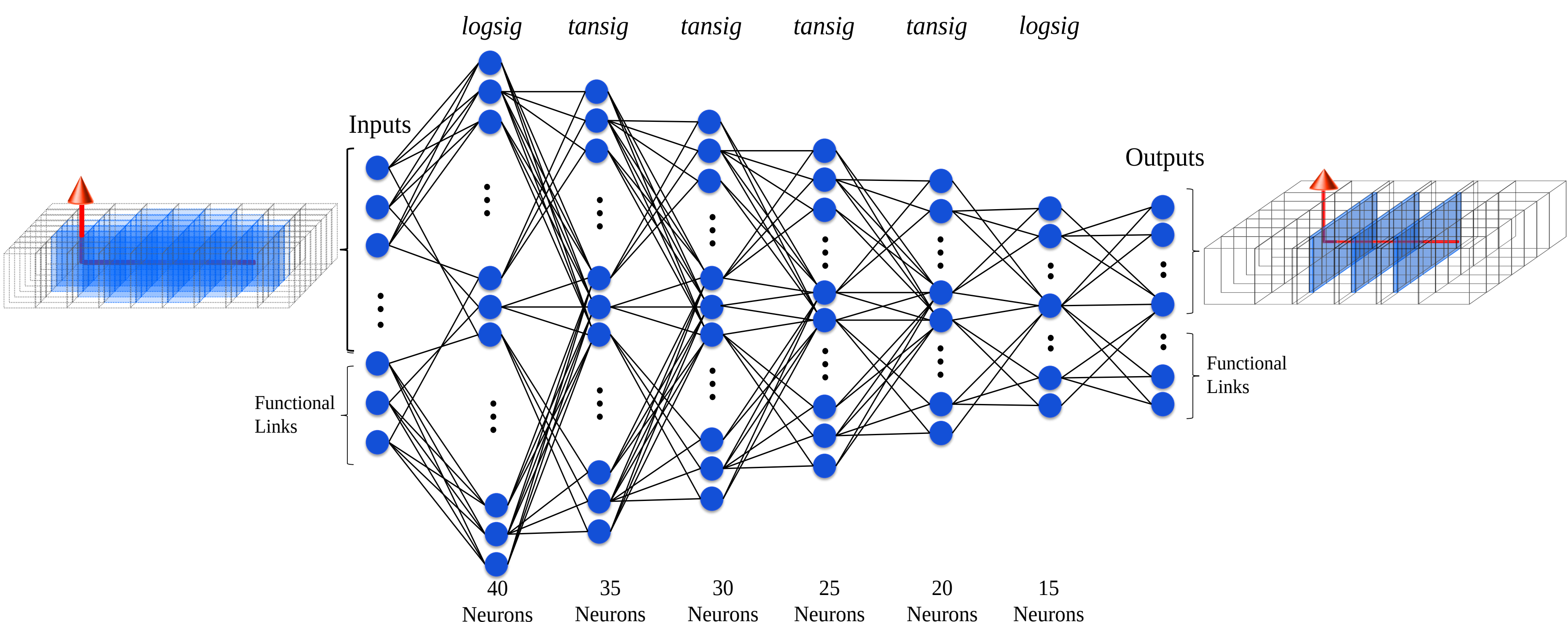
Development of ANNs

- Equivalency ANN
  - Transverse to Crushed zone



Development of ANNs

- Equivalency ANN
  - Crushed zone to Transverse



Outline

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Graphical User Interface

ShaleGasANNToolBox

ANN Toolbox for Hydraulically Fractured Horizontal Wells in Shale Gas Reservoirs

PENNSTATE 1855

Transverse Fracture Representation | Crushed Zone Representation

Simulate | Plot | Export Table to Excel | Reset All | Reset Design Characteristics | Help | Example

Reservoir Parameters

Reservoir Thickness (50-300 ft)	54.81
Compressibility of Formation (0.000005-0.000008 1/psi)	0.00000749
Matrix Permeability (0.0000001-0.01 mD)	0.0000594
Fracture Permeability (0.0001-0.2 mD)	0.0268
Matrix Porosity (2-16 %)	8.09
Fracture Porosity (0.1-3 %)	2.45
Natural Fracture Spacing (1-40 ft)	14.3
Reservoir Temperature (130-300 F)	175
Initial Reservoir Pressure (3,000-8,000 psi)	5807
Langmuir Pressure (200-800 psi)	491
Langmuir Volume (50-300 scf/ton)	63.8

Design Characteristics

Drainage Area Per Well (50-300 Acres)	85.47
Horizontal Well Length (900-2,168 ft)	1157
Number of Transverse Fractures (2-19 stages)	3
Hydraulic Fracture Spacing (100-300 ft)	278
Fracture Half Length (100-850 ft)	270
Hydraulic Fracture Permeability (10-1,000,000 mD)	1850
Well Flow Pressure (14.7-3,920 psi)	2829

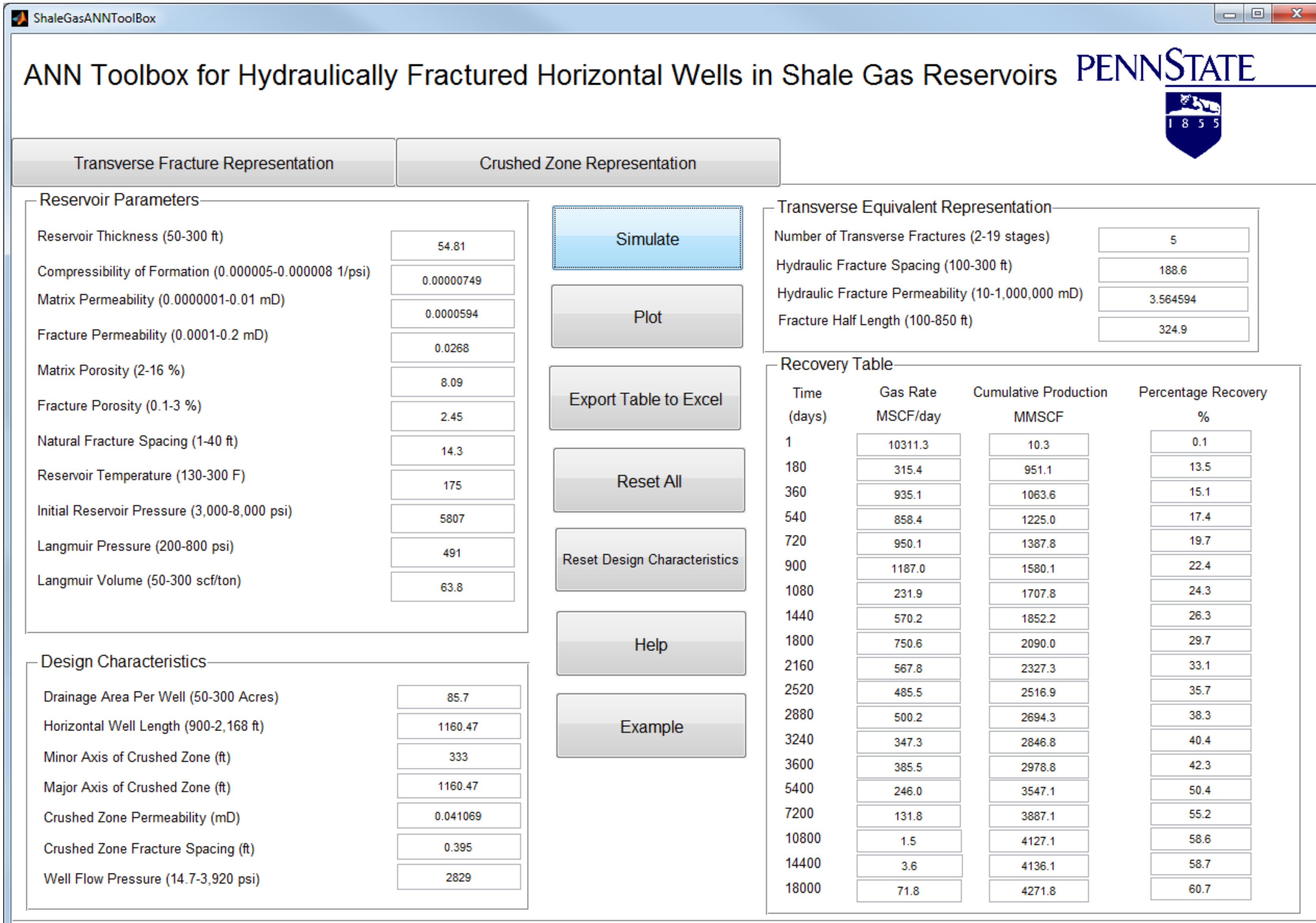
Crushed Zone Equivalent Representation

Minor Axis of Crushed Zone (ft)	333.0
Major Axis of Crushed Zone (ft)	1113.5
Crushed Zone Permeability (mD)	0.041069
Crushed Zone Fracture Spacing (ft)	0.395

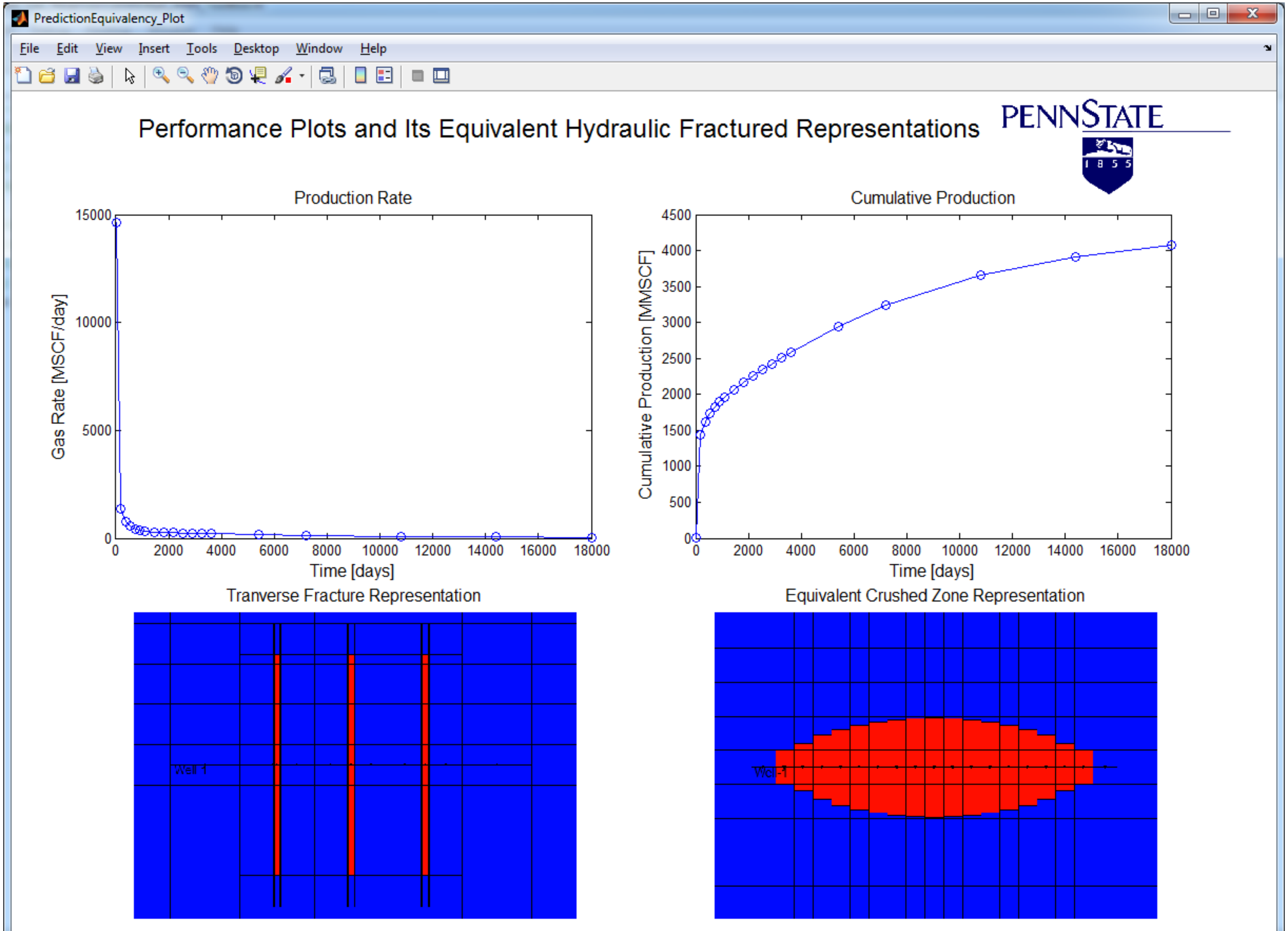
Recovery Table

Time (days)	Gas Rate MSCF/day	Cumulative Production MMSCF	Percentage Recovery %
1	14642.8	14.6	0.2
180	1344.0	1430.8	20.4
360	772.4	1621.3	23.1
540	561.2	1741.3	24.8
720	440.3	1831.5	26.1
900	354.6	1903.0	27.1
1080	319.1	1963.6	28.0
1440	270.9	2069.8	29.5
1800	253.0	2164.1	30.8
2160	251.8	2255.0	32.1
2520	236.0	2342.8	33.4
2880	224.5	2425.7	34.5
3240	227.4	2507.0	35.7
3600	217.7	2587.2	36.8
5400	178.6	2943.9	41.9
7200	144.7	3234.9	46.1
10800	88.4	3654.4	52.0
14400	53.6	3909.9	55.7
18000	35.8	4070.8	58.0

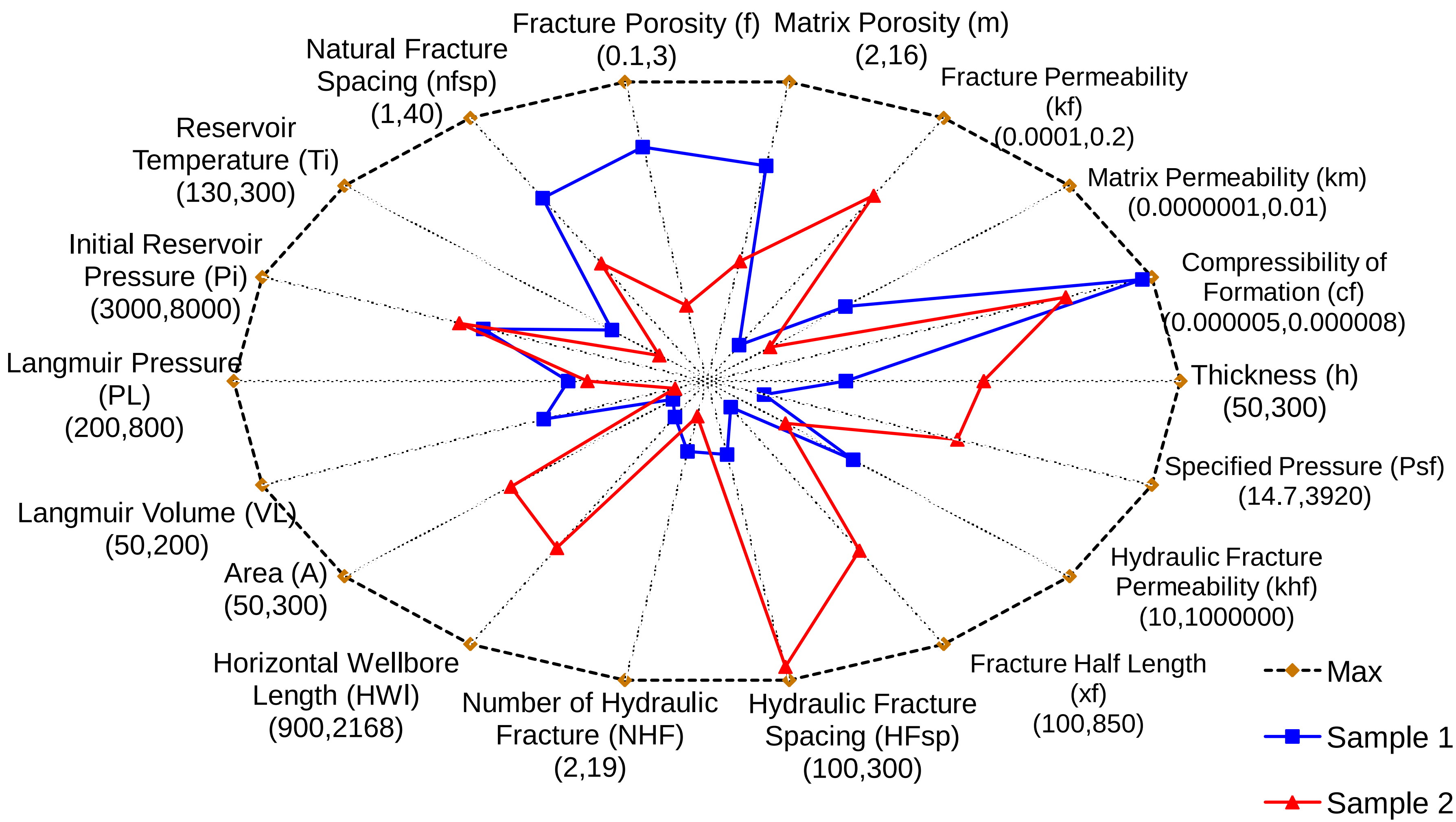
Graphical User Interface



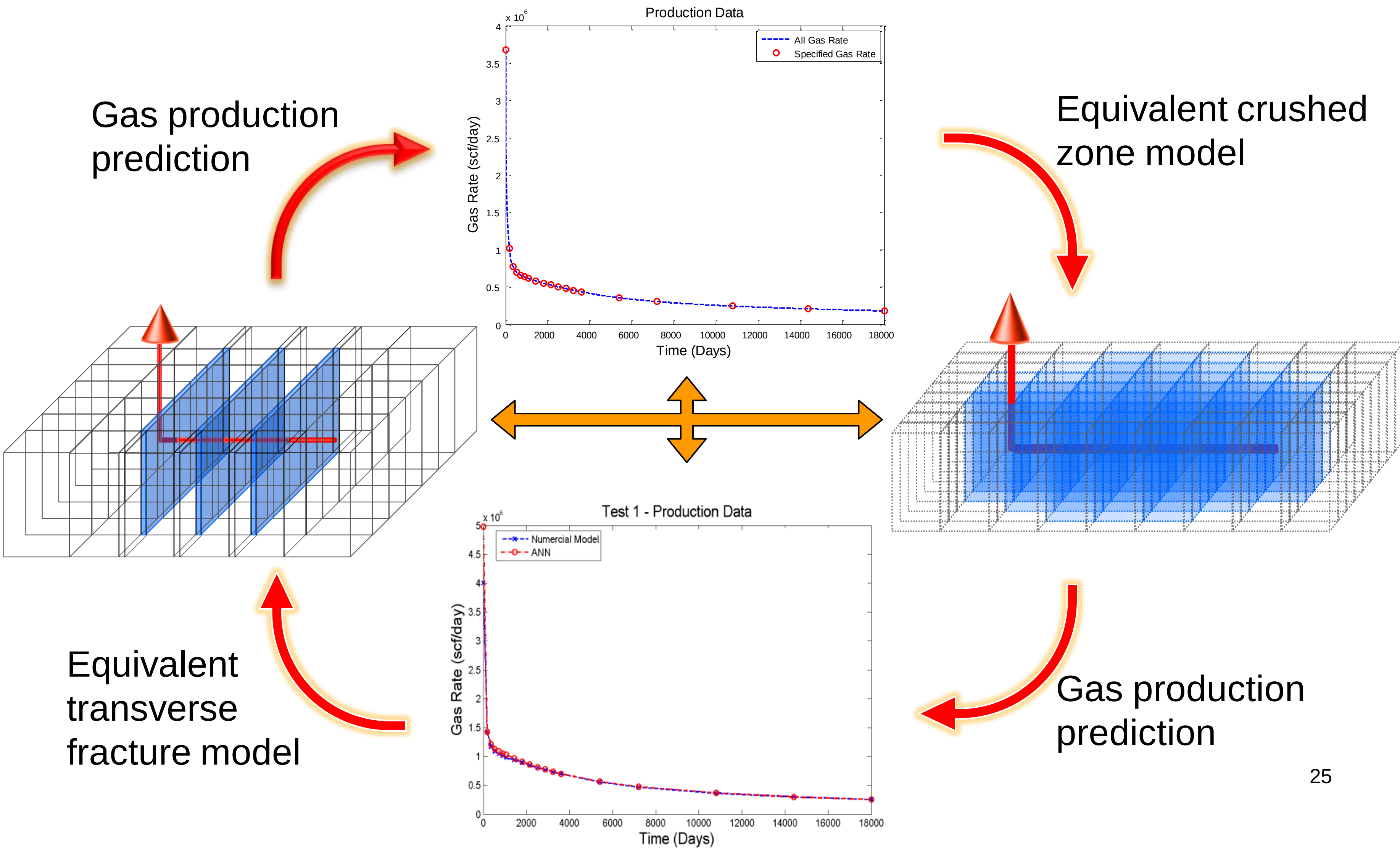
Graphical User Interface



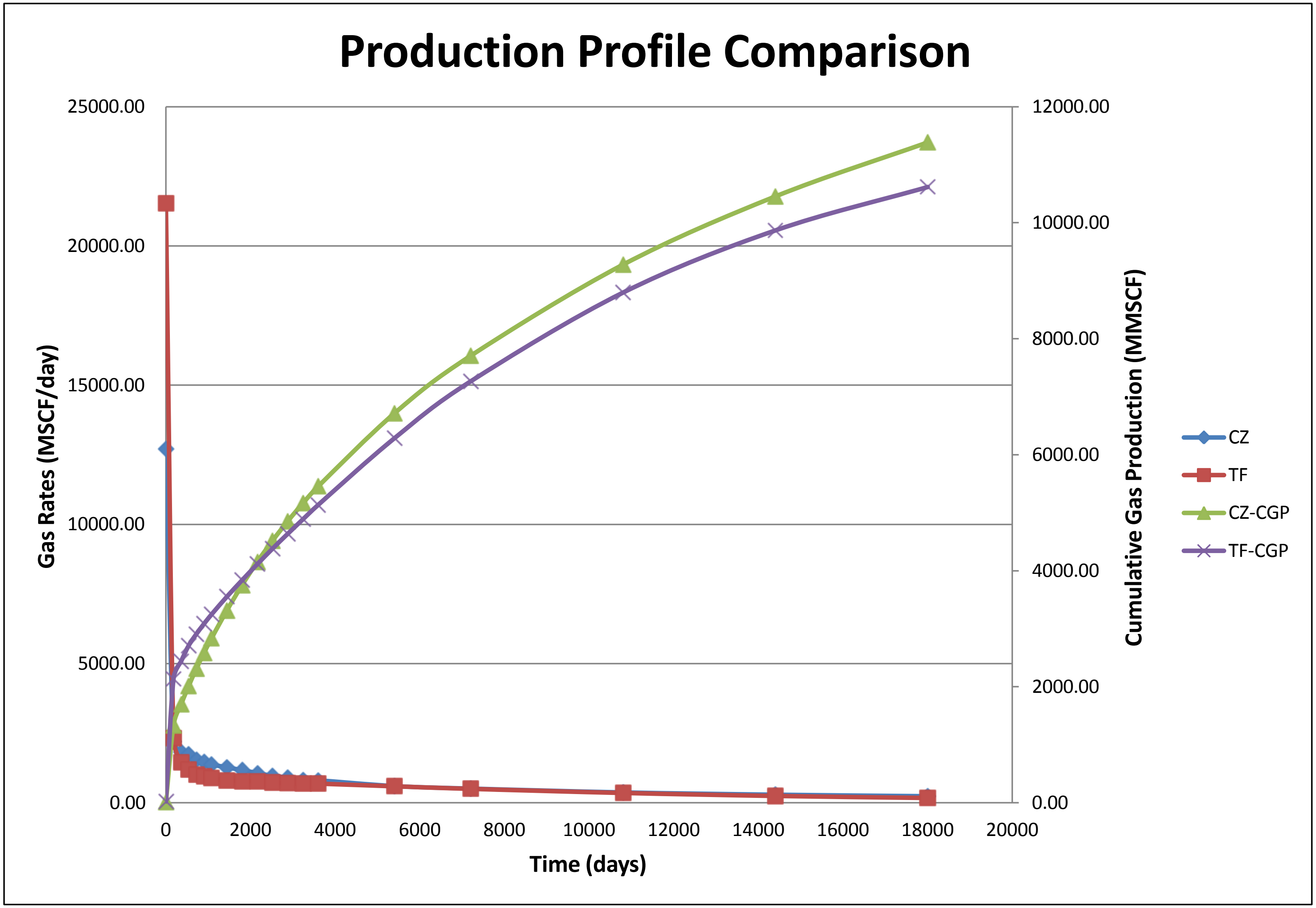
Range of Reservoir Parameters and Design Characteristics



Results and Discussion



Results and Discussion

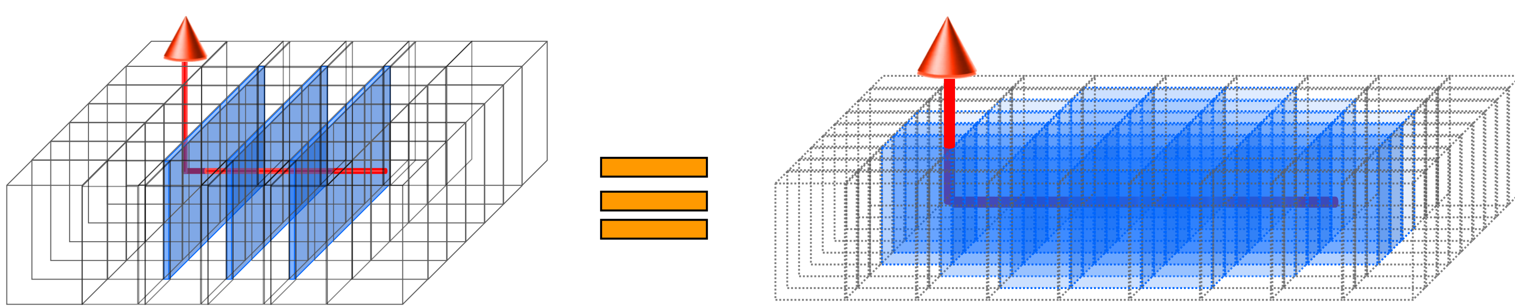


Results and Discussion

Equivalent Representations			
Transverse Fracture Representation		Crushed Zone Representation	
Number of Hydraulic Fracturing Stages	9	Minor Axis of Elliptical Zone (*ft*)	920
Distance Between Fracture Planes (*ft*)	207.9	Major Axis of Elliptical Zone (*ft*)	2222.7
Hydraulic Fracture Permeability (*mD*)	0.33941	Crushed Zone Permeability (*mD*)	0.048586
Fracture Half Length (*ft*)	385.4	Fracture Spacing in the Crushed Zone (*ft*)	0.01

Summary and Conclusions

- Four ANNs have been developed:
  - Gas Production Prediction ANNs
    - Transverse fracture representation
    - Crushed zone representation
  - Equivalency ANNs
    - Transverse to Crushed Zone
    - Crushed Zone to Transverse



Transverse Fracture Model   Crushed Zone Model

Summary and Conclusions

- The developed ANNs answer the forward-looking and inverse-looking problems for gas prediction using both representations and establish equivalency between them.

- The developed ANN toolbox can be effectively used in reservoir modeling studies of shale gas field development projects.