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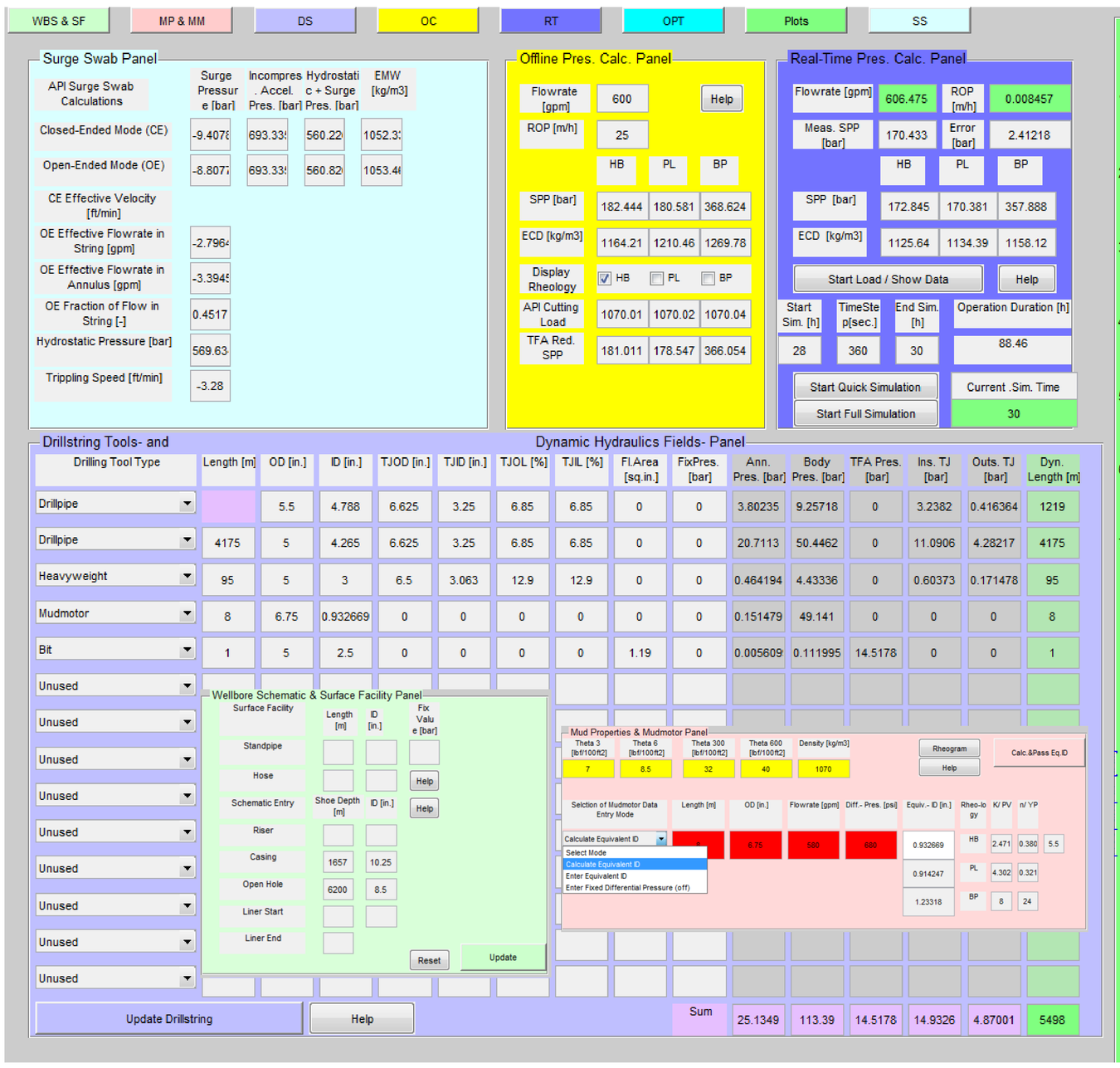
Towards Safer and Cost-efficient Construction of Geothermal Wellbores with a Real-Time Drilling Hydraulics Simulator, *Wisam Sindi*

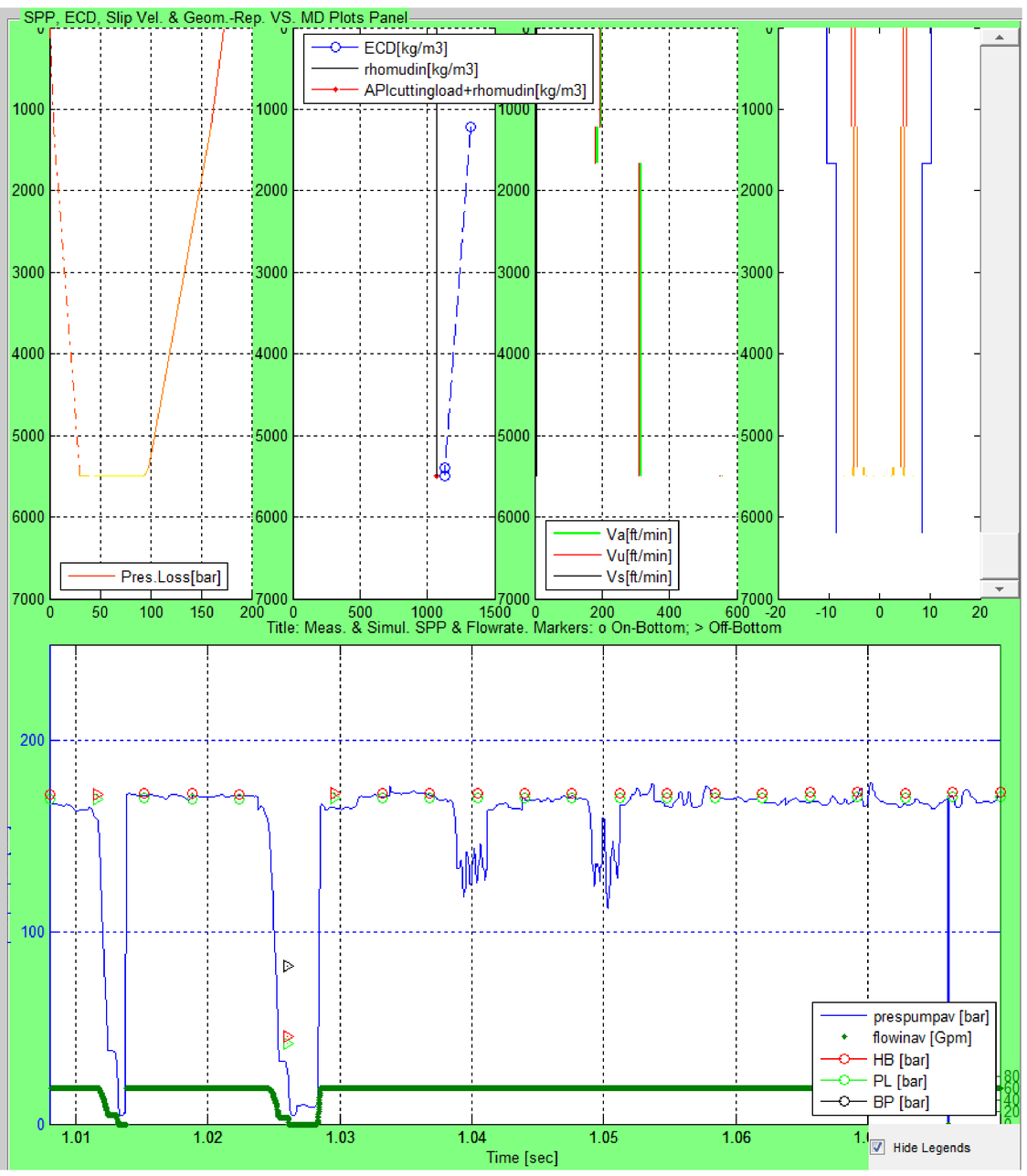
Introduction & Benefits of Modelling

- Optimize drilling by decreasing nonproductive time through timely recognition of incidents.
- Rig sensor data connected to mathematical models for predicting of key parameters in real-time, incl. SPP, ECD, surge pressure, cuttings transport conditions and flow regimes along the wellbore annulus
- Automated safe-guarding and safety triggering, e.g.: Limit the mud pump rate to keep the downhole pressure within limits.
- Matched model result serve to fill-in of sensor data in time and space.
- E.g. replace PWD when no mud pulse telemetry is possible.
- E.g. modelling ECD at the casing shoe when sensors are located much further towards BHA.
- Determine plugged bit nozzles.

Available Graphical User Interface (GUI) Panels:

i. Wellbore Schematic and Surface Facility
ii. Drillstring Tools and Dynamic Hydraulics Fields
iii. Mud Properties and Mudmotor
iv. Offline Pressure Calculation
v. Real-Time Pressure Calculation
vi. SPP, ECD, Slip and Geometry VS MD
vii. Surge Swab
viii. Options





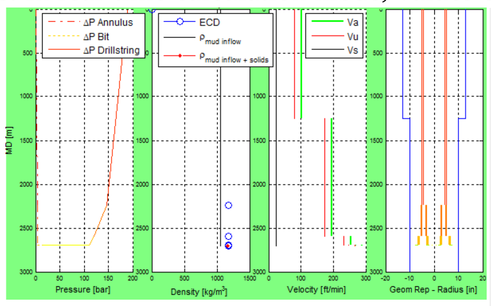
Tool GUI incl. panels for data entry and display of results. In real-time calculation mode, values & plots are updated in near real-time.

Drilling muds utilized in the field cases

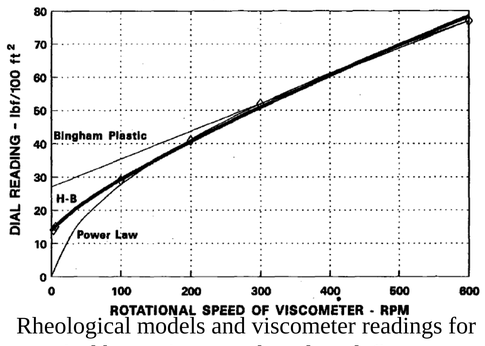
	Well-1	Well-2	Well-3	Well-4	Well-5
Mud Base	WBM	WBM	SBM	WBM	WBM
Mud Type	Ploymer	KCL-Polymer	Polymer	K2CO3-Polymer	K2CO3-Glycol
θ3 [lbf/100 ft²]	7	6	7	20	3
Θ6 [lbf/100 ft²]	8.5	8	8	21	4
Θ300 [lbf/100 ft²]	32	48	36	86	50
Θ600 [lbf/100 ft²]	40	70	58	140	77
PV [cP]	8	22	22	54	27
YP [lbf/100 ft²]	24	26	14	32	23
LSYP [lbf/100 ft²]	5.5	4	6	19	2
HB K' [lbf s^n/ft²]	2.47	1.15	0.21	0.33	0.62
HB n' [-]	0.38	0.58	0.79	0.852	0.88
PL K [lbf s^n/ft²]	4.30	1.61	0.49	1.075	1.02
PL n [-]	0.32	0.54	0.69	0.702	0.62
Gel Strength 10sec/10min [Pa]	5.3 / 5.8	6 / 8	5.3 / 13.4	9/44	4/5
Density [kg/m3]	1070	1320	1370	1550	1160
Oil [vol%]	0	0	64	N/A	N/A
Water [vol%]	92	82	18.5	N/A	N/A
Solids [vol%]	6	18	17.5	11.6	N/A
Lubricant [vol%]	2	0	0	N/A	N/A
Sample Point	Flowline & Active Pit	Sample Depth 2840 m RT	Flowline & Active Pit	Active Silo	Active Silo

Wellbore schematic, modeled depth-interval and operation-duration of the field cases

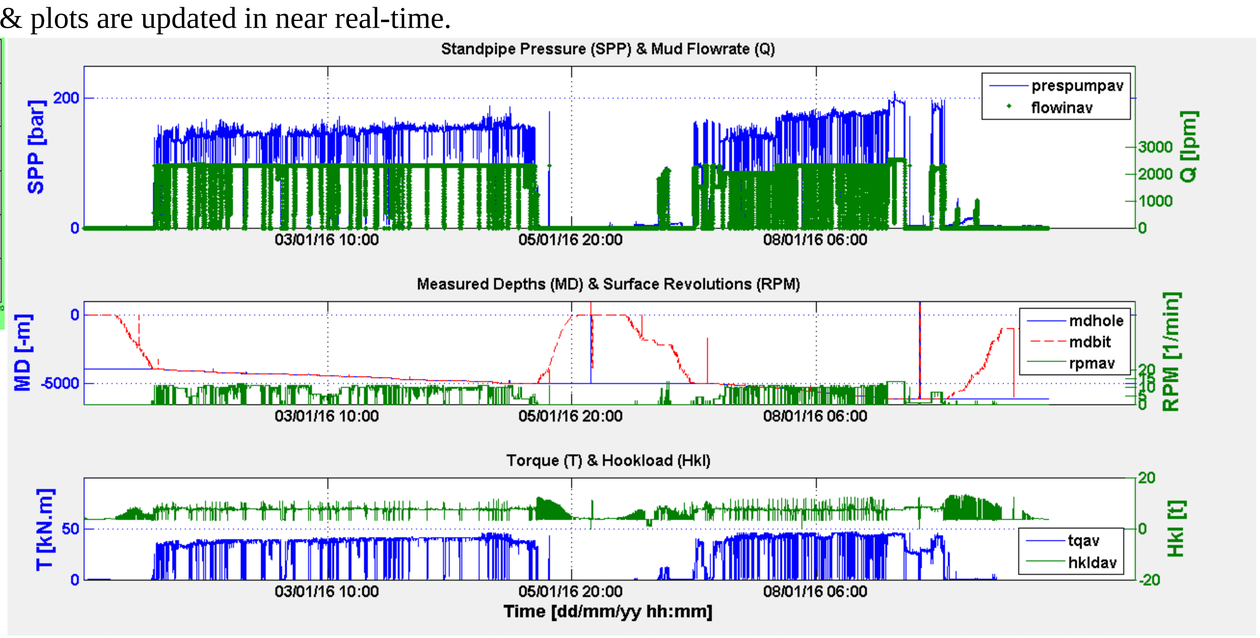
	Well-1	Well-2	Well-3	Well-4	Well-5
Mud Base	WBM	WBM	OBM	WBM	WBM
Riser Deph [m]/ ID [in]	-	-	2304/26	-	-
Csg Depth [m]/ Dia [in]	1660/10.3	1575/13.4	3305/19.5	2960/9.625	4850/7
OH Target ID [in]	8.5	10.6	18.1	8 3/8	5.875
Modeling MD Hole Start [m]	4050	2690	5350	2975	5050
Modeling MD Hole End [m]	6000	3050	6000	4160	5340
Modeling Drilled MD	1950	360	650	1185	290
Operation Duration [h]	230	91	15	45	162
Well Design	Horizontal, Conventional	Vertical, Conventional	Vertical, HTHP	Vertical until 3960, then slanted	Vertical until 3550, then sidetrack w/ const incl 22



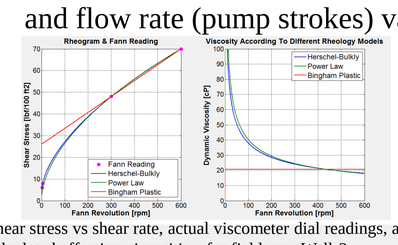
Calculated pressure losses, densities and velocities in the annulus, and idealized geometric representation of the wellbore-drillstring system (Radial dimensions of the tools are not to scale)



Rheological models and viscometer readings for a typical bentonite water-based mud. Source: Reed & Pilehvari (1993)



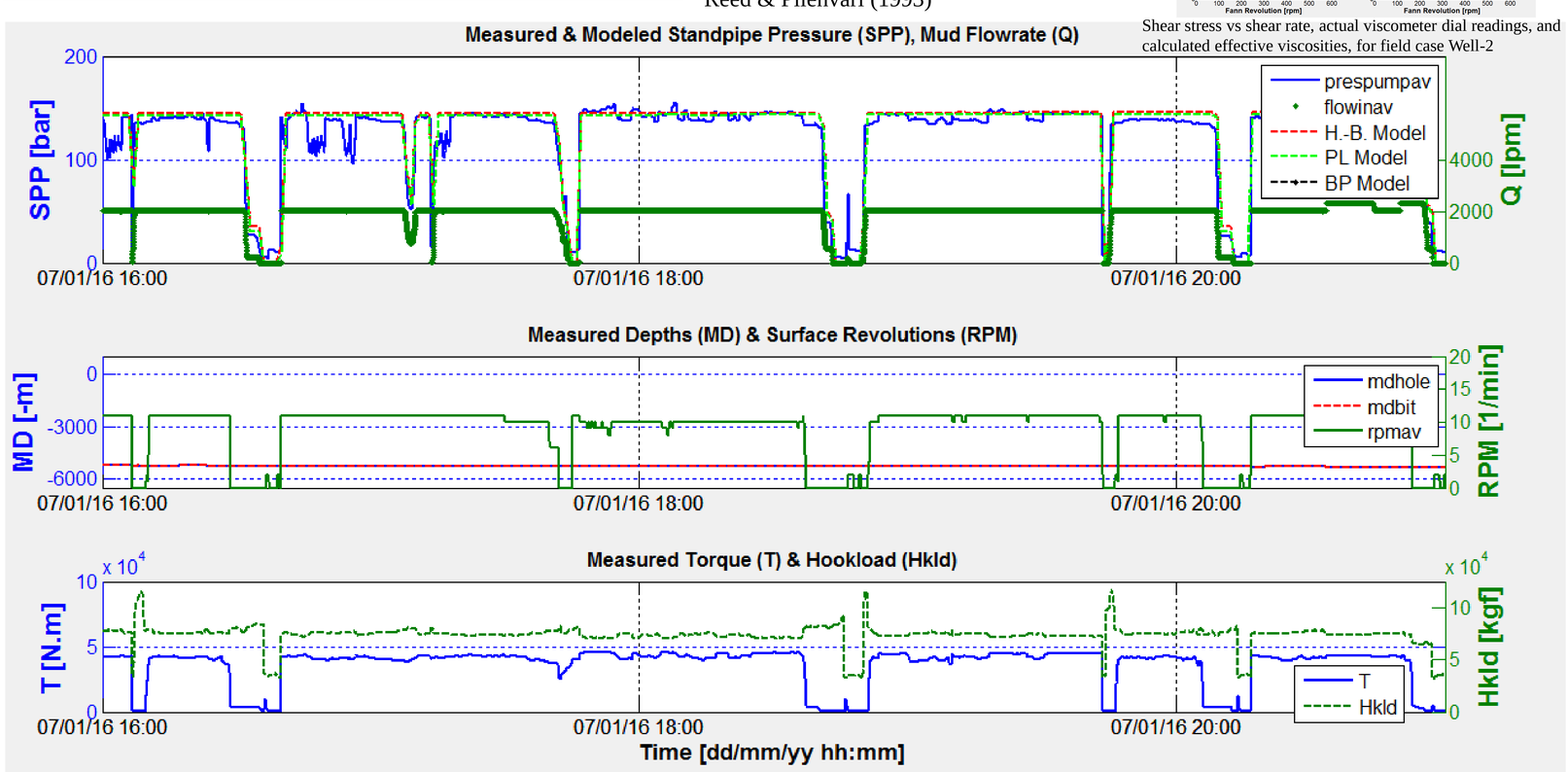
Rig surface sensor measurement data of field case Well-1 (Horizontal well, using WBM). Bit depth and flow rate (pump strokes) values are used by the solution.



Shear stress vs shear rate, actual viscometer dial readings, and calculated effective viscosities, for field case Well-2

Methodology, Results & Conclusion

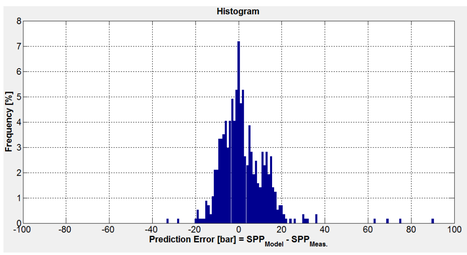
- Generate a geometrical representation of the wellbore & drillstring.
- Perform (real-time) hydraulics calculation using the position of the bit & flow rate from rig sensor data.
- Mud properties are obtained and deployed using the BP, PL and H.-B. rheology models, as suggested API RP 13D.
- ECD calc accounting for solids & measured real-time rate of penetration (ROP).
- Bit calculation accounts for total flow area (TFA).
- PDM / mud motor: dynamic calculation model is created using information from datasheet (bit torque and rpm are not available).
- The tool was validated with 500 hours of rig sensor data from 5 wellbores (4 conventional use WBM, 1 HPHT using OBM).
- For conventional drilling using water-based mud, prediction of the SPP within a mean deviation of 10 bars is possible.
- Future work consists of incorporating pressure & temperature effects on mud properties, torque and drag (TaD), and managed pressure drilling (MPD).



Measured and modelled SPP for 5 hours of operation, including alternating on-bottom and off-bottom operations, making connections and downlinking, for field case Well-1

Well	Error [bar]	H.-B.	PL	BP
Well-1 (Conventional, WBM)	Mean	9.8	8.3	138.1
	Med	7.4	5.8	161.3
	Std	10.2	9.6	91.4
Well-2 (Conventional, WBM)	Mean	6.8	8.0	26.5
	Med	4.2	6.7	28.8
	Std	12.5	12.2	19.6
Well-3 (HPHT, OBM)	Mean	37.4	48.5	16.8
	Med	55.2	76.0	18.7
	Std	28.0	37.5	10.8
Well-4 (Conventional, WBM)	Mean	8.5	20.8	44.0
	Med	6.8	20.2	44.8
	Std	8.7	10.2	12.2
Well-5 (Conventional, WBM)	Mean	8.2	7.9	77.6
	Med	6.2	4.1	77.7
	Std	8.6	10.2	18.6

Mean, median and the standard deviation of the modeling results for all 5 field cases



Histogram for model-prediction error for H.-B. for field case Well-2

References
API RP 13D. (2010). Recommended Practice 13D, Rheology and Hydraulics of Oil-Well Drilling Fluids. Washington DC: API.
Reed & Pilehvari (1993): Reed, T. D., & Pilehvari, A. A. (1993). A New Model for Laminar, Transitional, and Turbulent Flow of Drilling Muds. . Society of Petroleum Engineers. doi:10.2118/25456-MS.