HALLIBURTON

A Call to Modernize the Drilling Industry's Methods of Calculating Circulating Hydraulics

Terry Hemphill

Global Advisor, Wellbore Management

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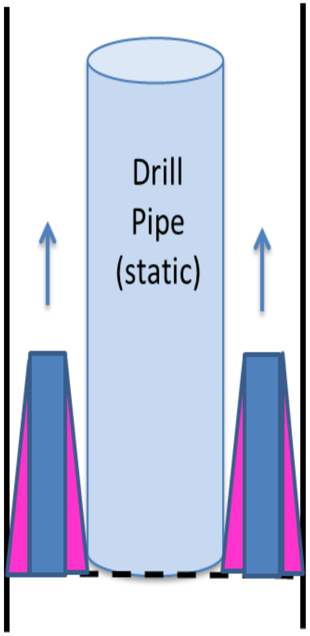
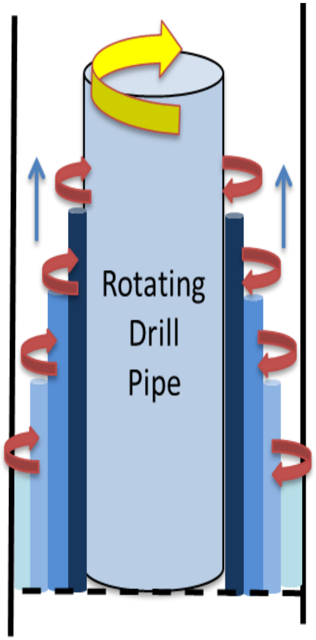
Objectives

- Review pressure drop calculations—laminar flow
- Propose a streamlined method for calculating pressure drop
  - No correction factors
  - No patches
- Base all modeling on the Herschel-Bulkley (HB) model as outlined in API RP13D (2006, 2010)
- Demonstrate use for axial and helical flow



Axial flow



Helical flow

Number of Pressure Drop Equations in Prominent Technical Resources (Laminar Flow)

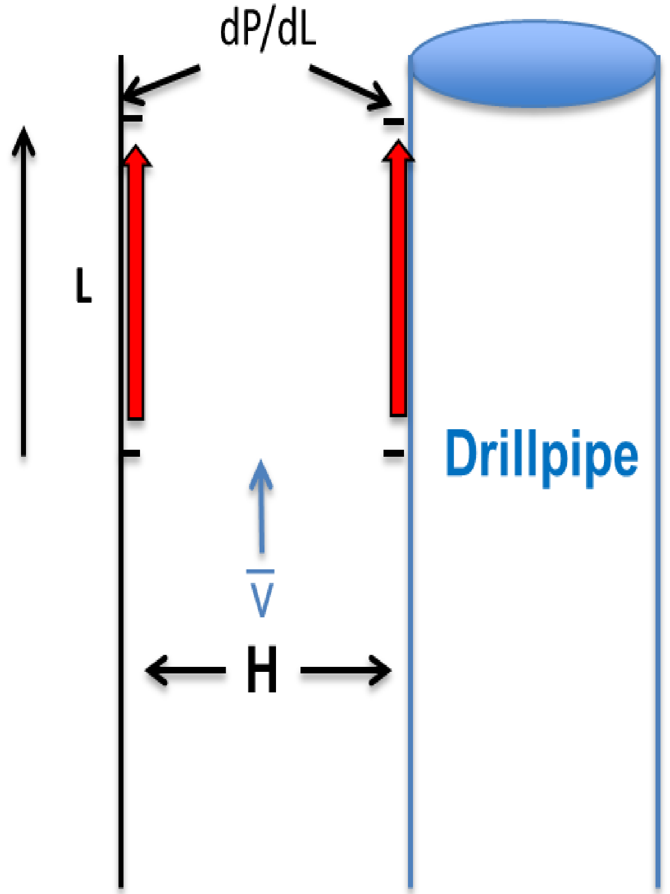
• *Applied Drilling Engineering* (SPE)	> 40
• SPE 25456 (Reed/Pilehvari 1993)	12
• *API Recommended Practice 13D*	> 10
• *Handbook of Fluids in Motion*	6 (HB modeling)

General Descriptions of Equations in Older Publications

- Fluid shear rate at the wall
- Shear stress at the wall
- Shear rate correction factors
- Hole geometry correction factors
- Drillpipe roughness factors
- Friction factors
- For concentric drillpipe only
- Numerous patches to older equations

How Is Pressure Drop Conventionally Calculated?

- **Shear rate at the walls**
  - $\gamma = 8 * v / H$, or
  - $\gamma = 96 * v / H$, or
  - Some variant thereof (API 13D RP)
- **Shear stress at the walls**
  - $T_{wall} = T_0 + K * \gamma^n$
- **Pressure drop at the walls**
  - $dP / dL = 2 * T_{wall} / H$
- **All pressure drop generated at the walls**
- **No drillpipe rotation, eccentricity considered**



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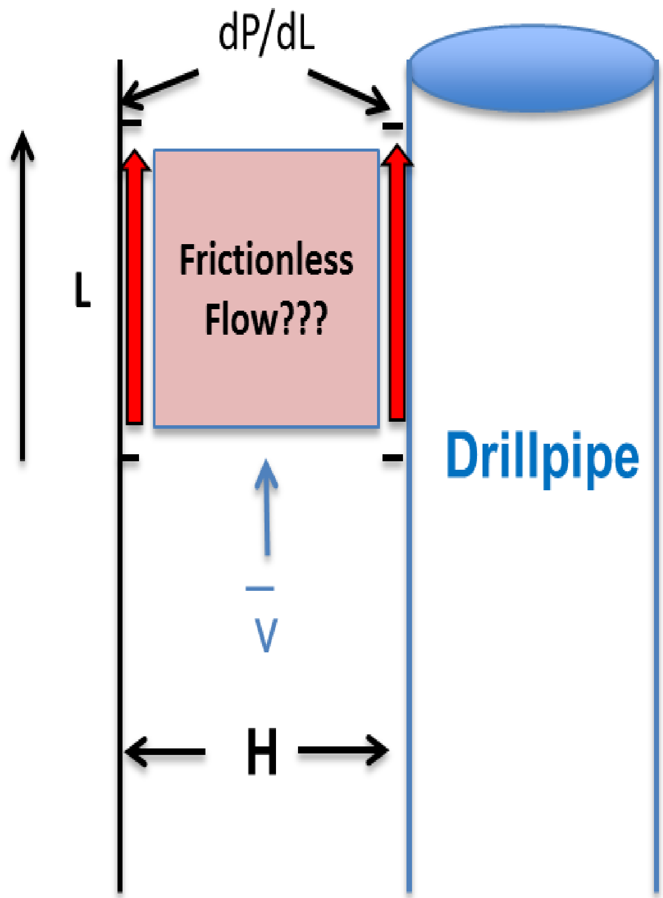


Fundamental Problems with Conventional Calculations

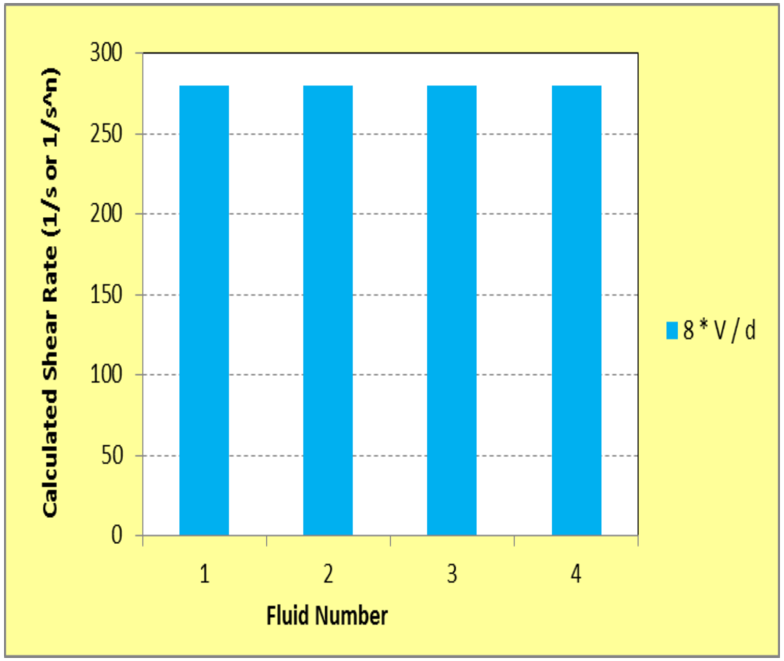
- Shear rate at the walls independent of fluid properties.
  - Given same average velocity and gap length, all fluids will have the same shear rate at the walls – **Newtonian fluid modeling.**
- Given a measured or calculated dP/dL, when recalculating dP/dL at the walls, results are ±95% of original dP/dL.
- Drillpipe eccentricity and rotation of drillpipe not considered.
- No provision for any friction in the moving fluid layers in the area away from the walls.

What's Wrong with Using Newtonian Fluid Modeling to Describe Drilling Fluids?

- Newtonian fluids can have no yield stress (tau zero).
- Newtonian fluids can have only one shear rate, one viscosity.
- Newtonian-based fluid modeling assumes 'frictionless flow' in the non-wall sections of the annulus
- Newtonian fluid modeling cannot accurately describe drilling fluid flow behavior.

Shear Rate at the Wall Calculations – Axial Flow

- Rabinowitsch-Mooney equation derived from Newtonian fluid modeling
- $\gamma = 8 \cdot V/d$
  - or $\gamma = 96 \cdot V/d$
  - or $\gamma = 1.6 \cdot G \cdot V / d_{hyd}$
- Shear rate independent of fluid rheological parameter values
- Four different fluids, same results (SPE 181439)



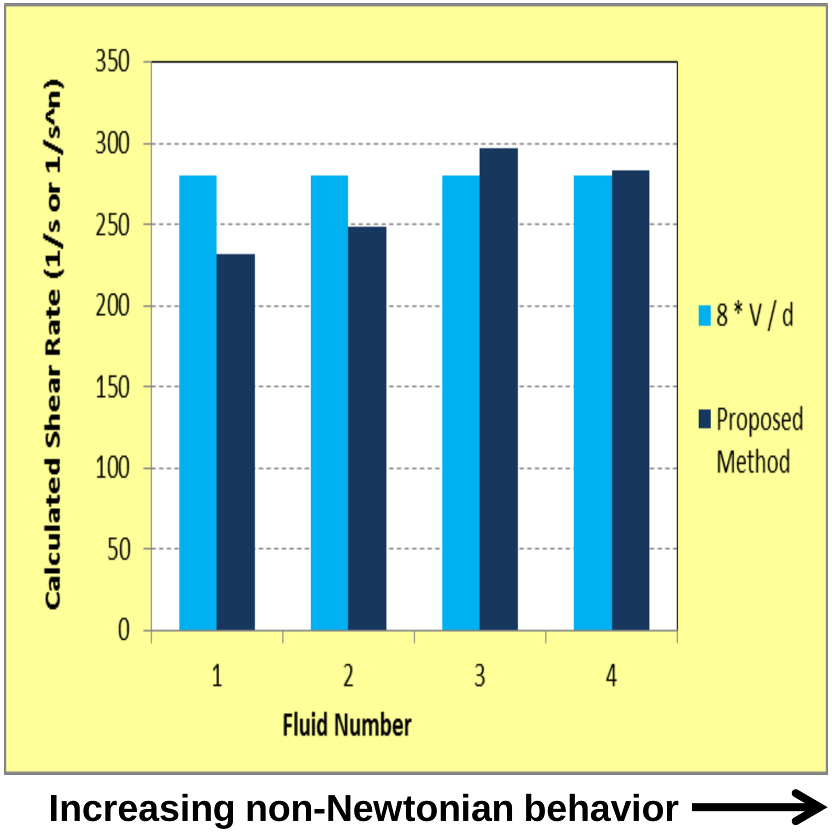
Concentric case

Shear Rate at the Wall Calculations – Axial Flow

- Shear rates are dependent on rheological parameter values

- Same four fluids using proposed method to calculate shear rate at the wall

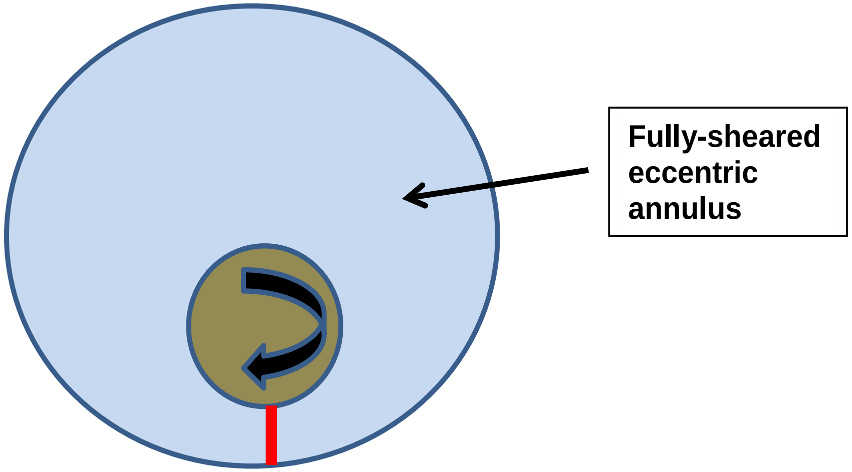
- 4 different shear rates differences 3 to 50/s^n



Concentric case

Effect of Drill Pipe Eccentricity on Pressure Drop

- Conventional drilling is nearly always performed with drillpipe rotation.
- Drillpipe eccentricity should be taken into account.
- Solution for eccentric annular geometry (Iyoho and Azar, 1981).
- Recommended levels of ε (refer to SPE 176451)



Effect of Drill Pipe Eccentricity on Pressure Drop

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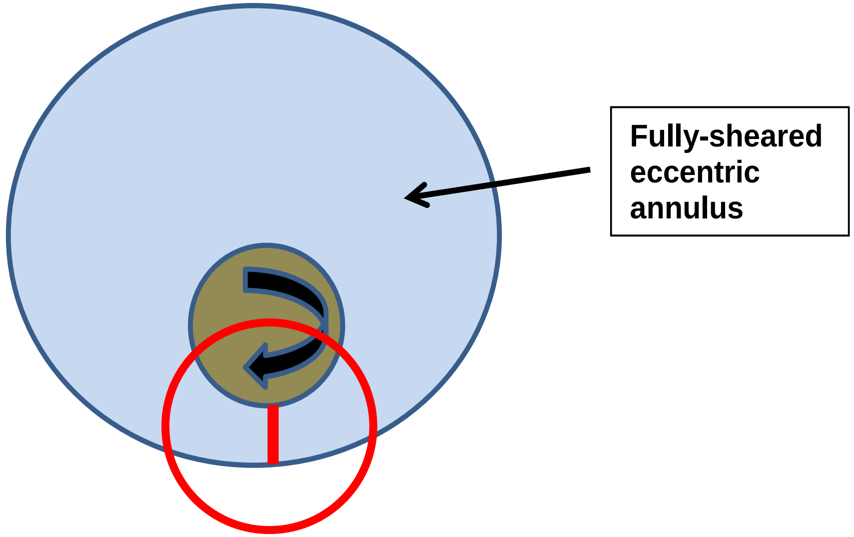
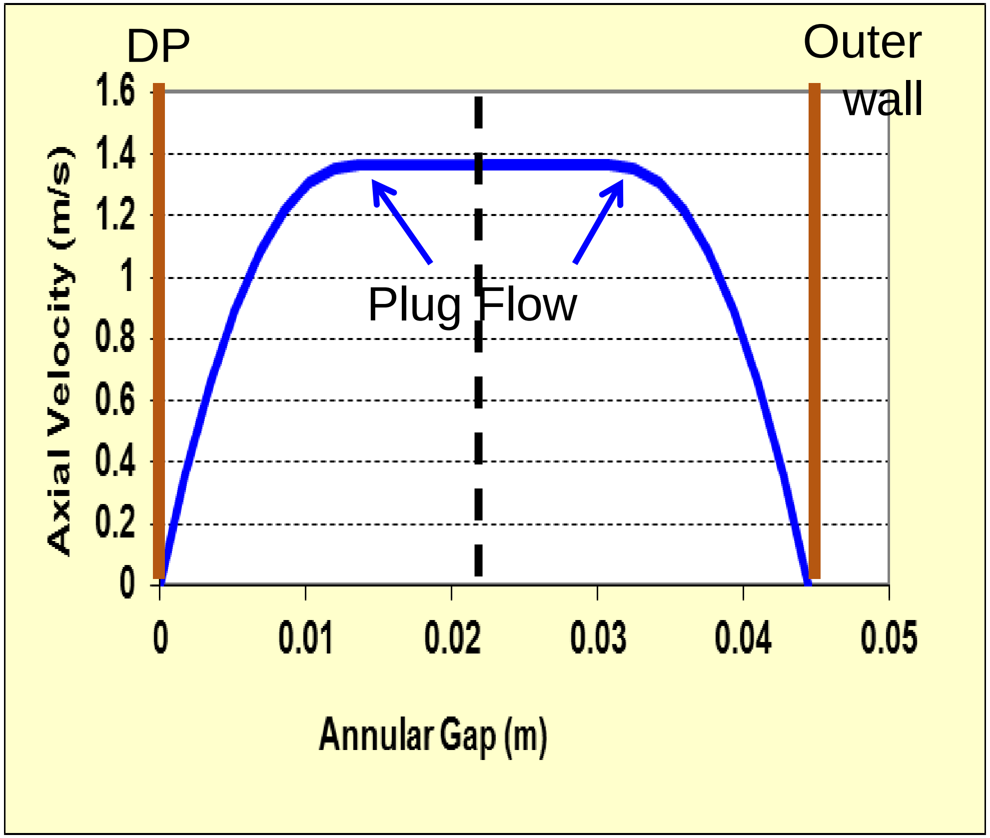
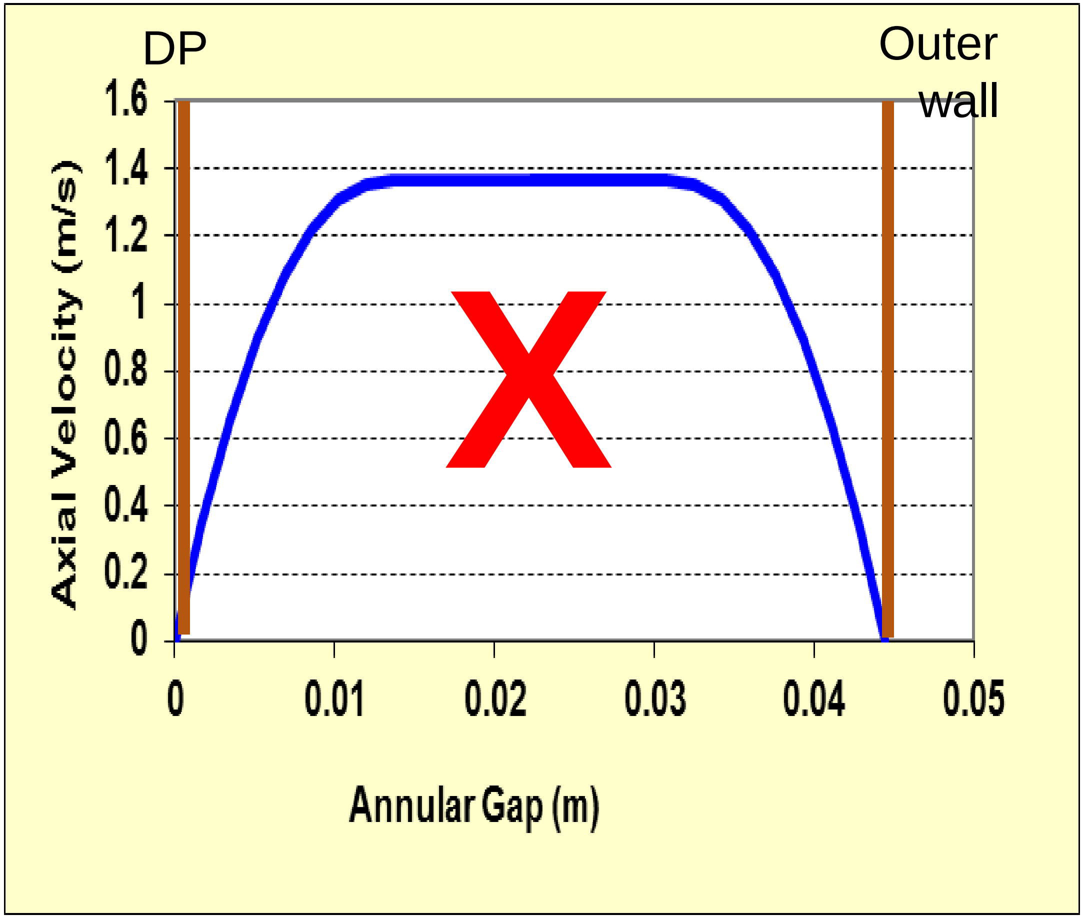
- Drillpipe eccentricity should be taken into account.
- Solution for eccentric annular geometry (Iyoho and Azar, 1981).
- Recommended levels of ε (refer to SPE 176451)
- Narrowest gap determines the pressure drop for given geometry and flow rate.



Conventional Modeling of Axial Flow (Laminar)
No Drillpipe Rotation



Modeling of Helical Velocities Produced with Drillpipe Rotation



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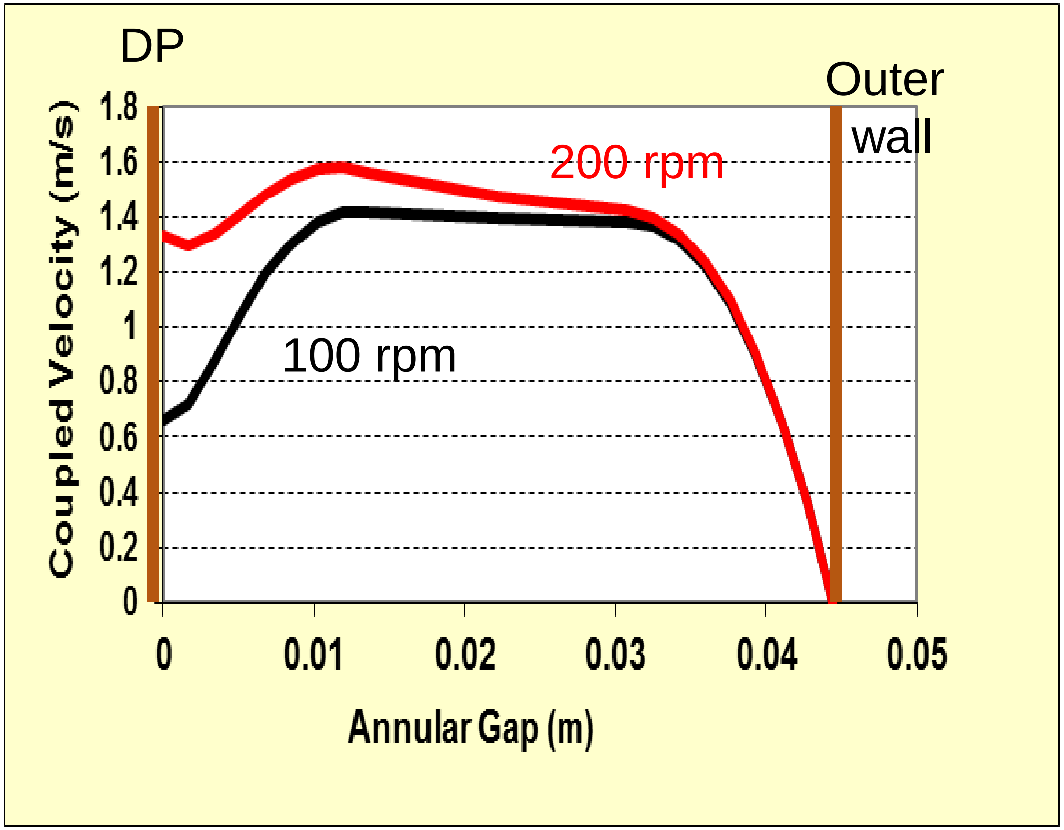


Proposed Method for Calculation of Pressure Drop - Laminar Flow Only

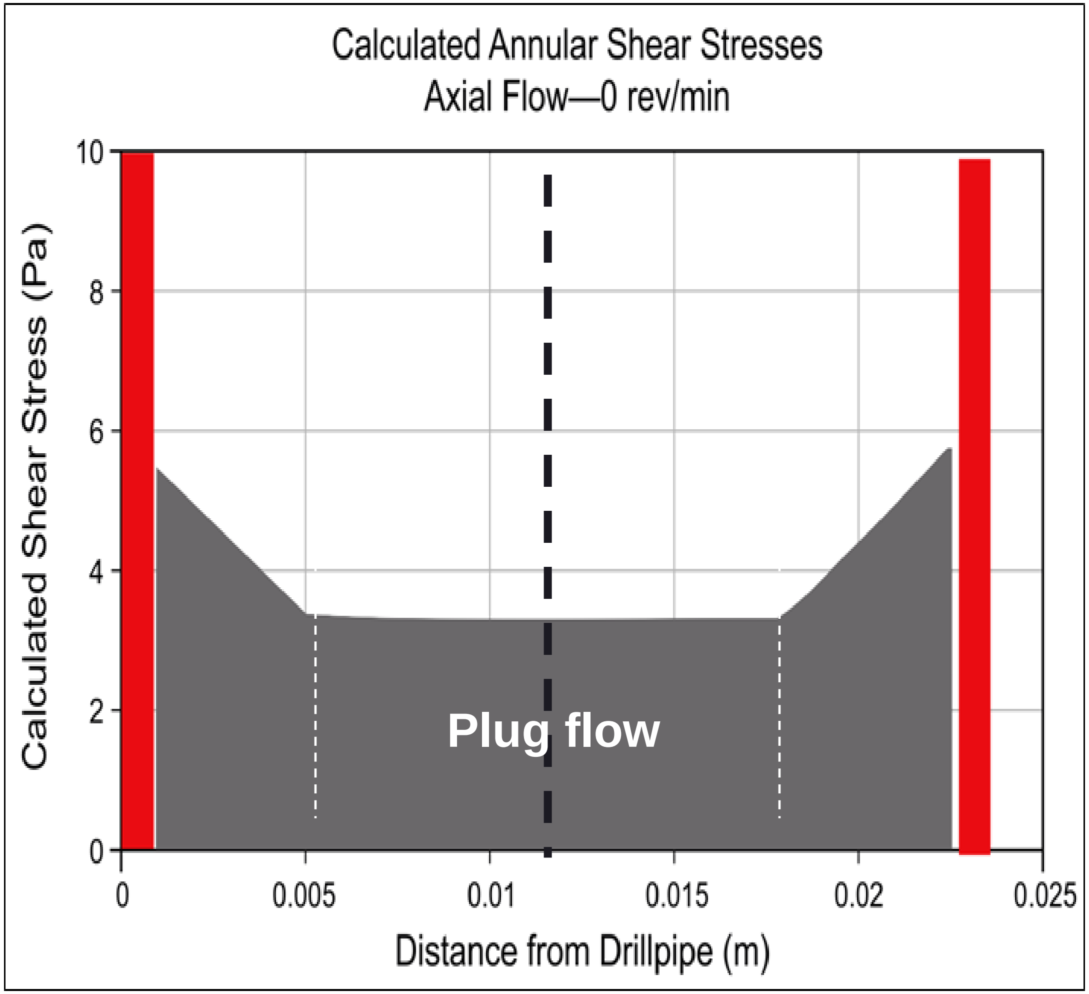
- Numerical solution required when using the HB model.
- Use equations in Appendix, SPE 181439
  1. Determine the width of the narrowest gap due to drillpipe eccentricity.
  2. Create calculation grid across the narrow gap.
  3. Calculate point velocities of moving fluid.
  4. Calculate average shear rates between adjacent cells.
  5. Calculate average shear stresses.
  6. Calculate pressure drop at the conduit walls.
  7. Calculate the pressure drop in the non-wall sections.
  8. Calculate the total pressure drop.

Example Spreadsheet for Calculation of Pressure Drop - Laminar Flow Only (SPE 173054)

Drill Pipe RPM = 0 (axial flow only)				Drill Pipe RPM = 100 (helical flow)			Drill Pipe RPM = 200 (helical flow)		
Segment #	Pt. Veloc. (m/s)	Sh. Rate (1/s^n)	Fluid tau (Pa)	Pt. Veloc. (m/s)	Sh Rate (1/s^n)	Fluid tau (Pa)	Pt. Veloc. (m/s)	Sh. Rate (1/s^n)	Fluid tau (Pa)
1(wall)	0.00			0.66			1.33		
2	0.01	23	5.4	0.64	42	6.9	1.29	75	9
3	0.03	19	5.1	0.62	40	6.7	1.24	73	8.9
4	0.03	15	4.8	0.6	38	6.6	1.2	71	8.8
5	0.04	12	4.5	0.58	36	6.5	1.16	70	8.7
6	0.05	9	4.2	0.56	35	6.4	1.12	69	8.6
7	0.05	6	3.9	0.54	34	6.3	1.08	68	8.5
8	0.05	3	3.6	0.52	33	6.2	1.04	67	8.5
9	0.05	1	3.3	0.5	33	6.2	1	66	8.4
10	0.05	0	3.2	0.31	31	6.1	0.61	62	8.2
11	0.05	0	3.2	0.14	28	5.9	0.26	56	7.8
12	0.05	1	3.3	0.12	27	5.8	0.23	54	7.7
13	0.05	3	3.6	0.11	27	5.8	0.19	54	7.6
14	0.05	6	3.9	0.09	27	5.8	0.16	53	7.6
15	0.04	9	4.2	0.07	28	5.8	0.13	53	7.6
16	0.03	12	4.5	0.06	29	5.9	0.1	54	7.6
17	0.03	15	4.8	0.04	30	6	0.07	54	7.7
18	0.01	19	5.1	0.02	32	6.1	0.03	55	7.7
19 (wall)	0.00	23	5.4	0	34	6.3	0	56	7.8

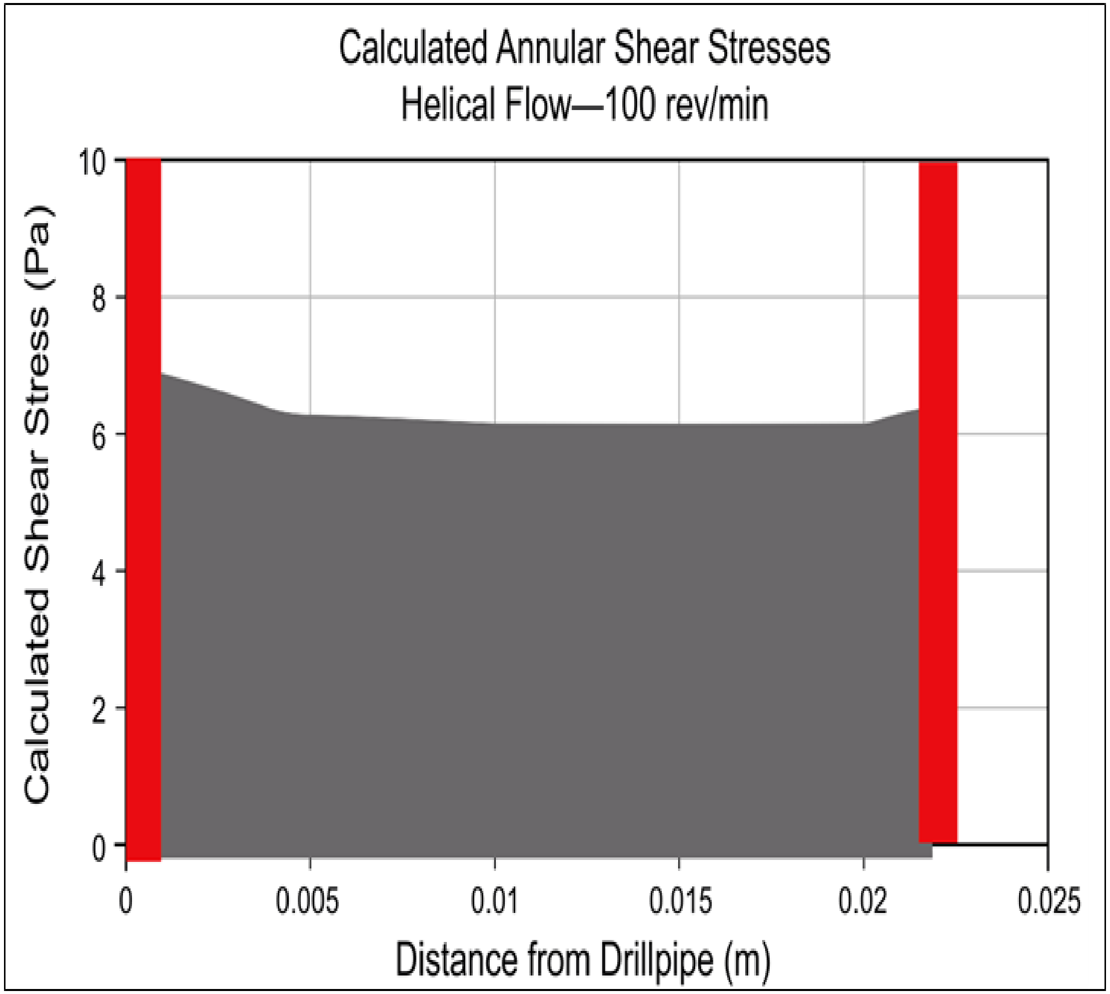
Pressure Drop Modeling for Fluids in Axial Flow (SPE 173054)

- Shear stresses at two walls are equal in value.
- Plug flow zone is in the center
- There is an axis of symmetry.



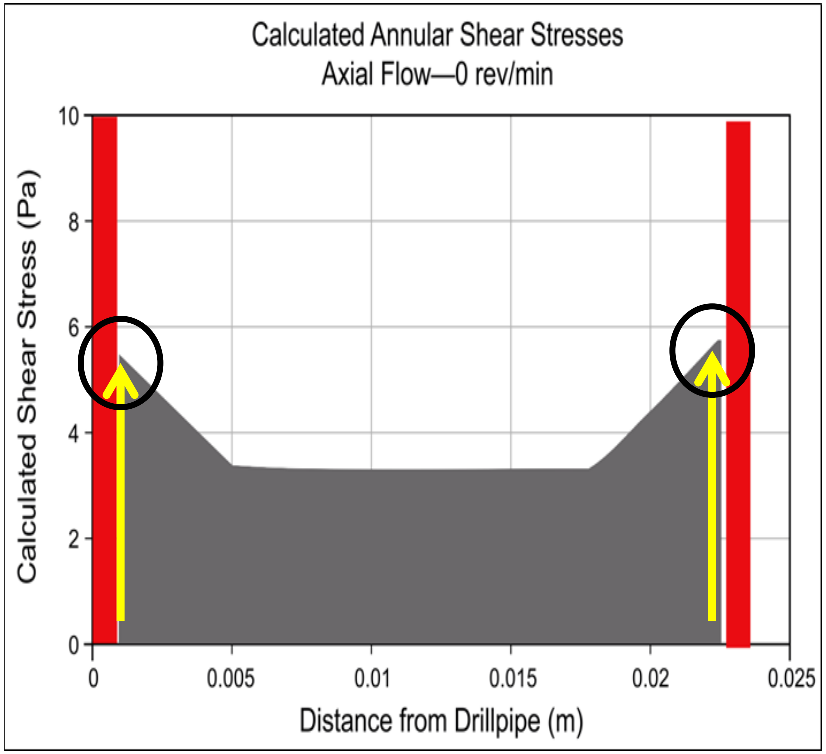
Effect of Drill Pipe Rotation on Pressure Drop (SPE 173054)

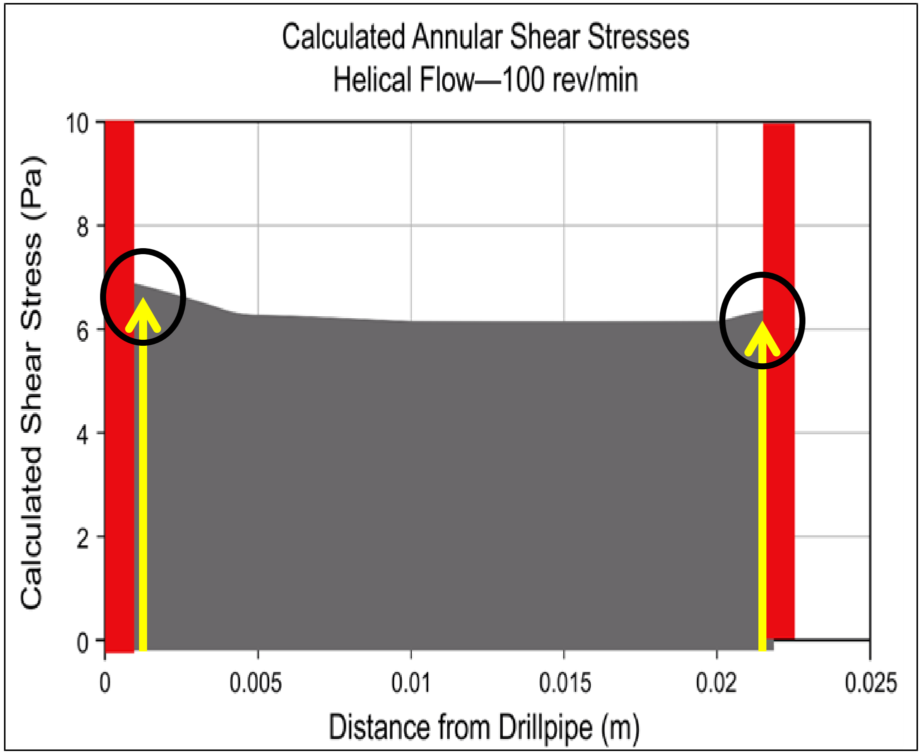
- Rotation of DP combined with axial flow produces helical flow.
- Shear stresses at two walls are no longer equal in value.
- No axis of symmetry.
- Increased friction in non-wall area as well.



Friction in the Non-Wall Areas

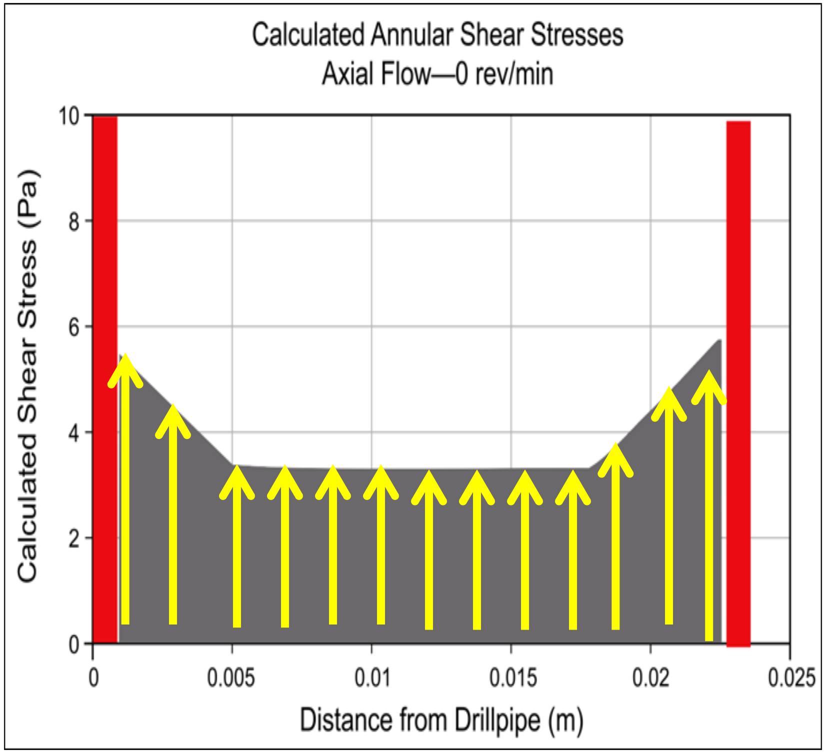
- No fluid movement until there is enough force to push the entire fluid across the gap at the same time.
- No pressure drop until 100% fluid movement.

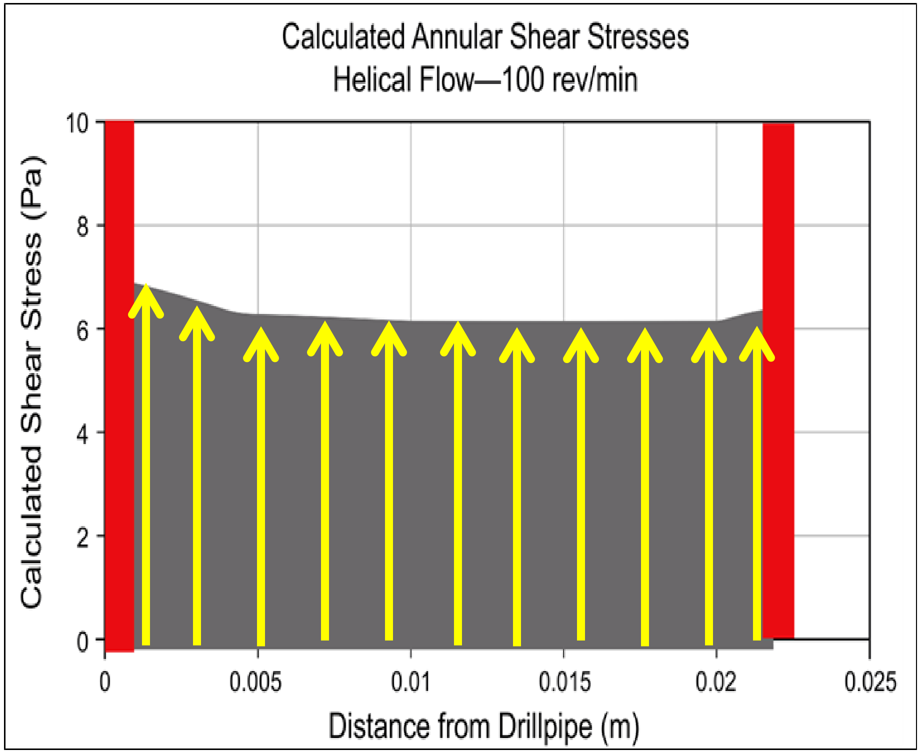




Friction in the Non-Wall Areas

- Force required to move fluid in non-wall sections – they have shear stresses also.
- Pressure drop in non-wall areas can be calculated using the missing ±5% pressure drop (SPE 173054).





Conclusions and Recommendations

- Shear rates for common drilling fluids calculated using Newtonian-derived equations are incorrect, thereby rendering pressure drop results suspect; errors cascade.
- Various patches added over the years unnecessary.
- Straightforward calculation methodology proposed for fluids well-described by Herschel-Bulkley rheological model.
- Drillpipe eccentricity should be taken into account
- Need to account for pressure drop consumed in pushing the non-wall fluid up the wellbore.
  - Small effect in axial flow.
  - Increased importance in helical flow with rotating drillpipe.

An Appeal to API Subcommittee 13 Drilling Fluids

It is time to revise API Recommended Practice 13D "Rheology and Hydraulics of Oil-well Fluids". The long-feared oil industry crew change is upon us now.

- Shear rate calculations derived from Newtonian modeling need to be revised.
- Drillpipe rotation is nearly always involved in drilling, yet:
  - ➢ The hydraulics of drillpipe rotation is not handled in 6th Edition (May 2010).
  - ➢ There is only a placeholder for rotation effect in the latest document (originally placed there in the 2006 edition!).
  - ➢ Recommended levels of ε by hole angle proposed (refer to SPE 176451).

Acknowledgements / Thank You / Questions

The presenter thanks SPE - GCS for providing this technical forum.