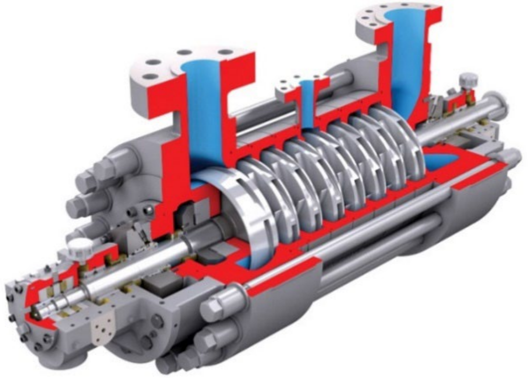
SCREW PUMPS IN HEAVY OIL PIPELINES

Luis Martinez P.Eng. MBA



CALGARY PUMP SYMPOSIUM 2024

Presenters

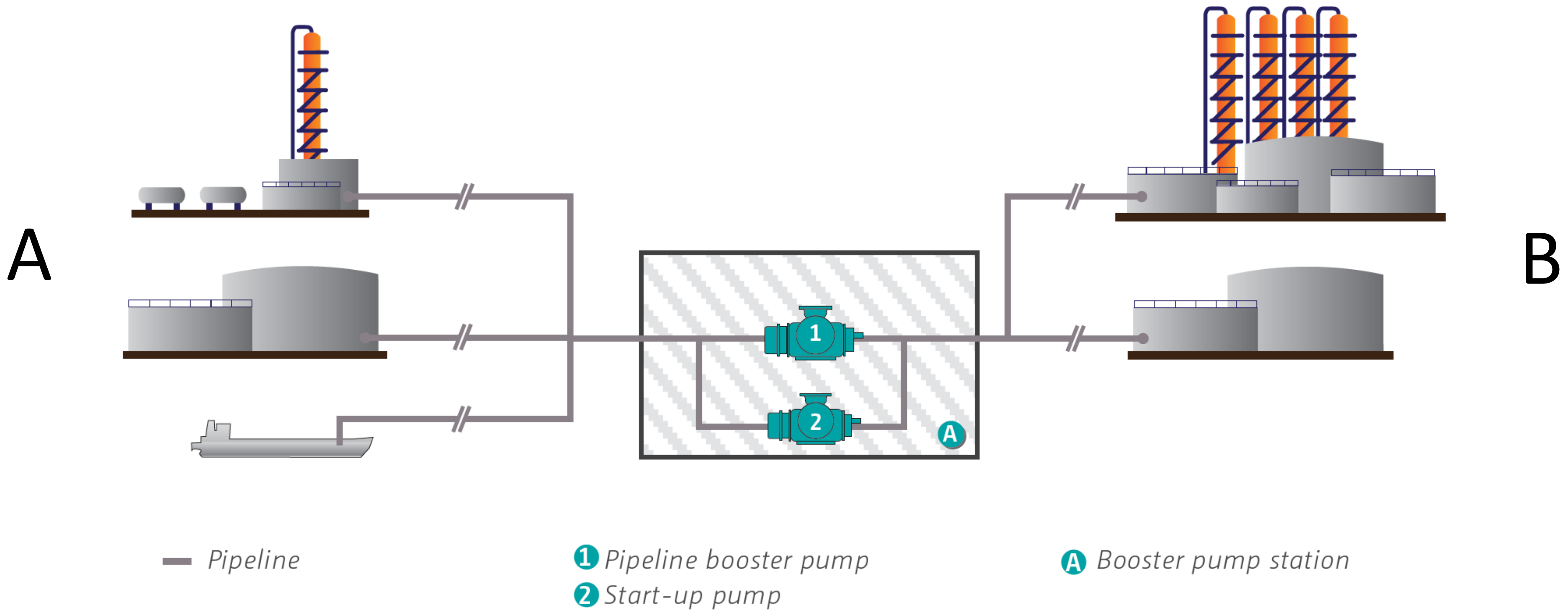
Luis Martinez P.Eng, MBA	Bachelor degree in Mechanical Engineering, with over 25 year's experience with O&G pumping equipment and facilities. Involved in the complete life cycle of the equipment, from the applications and engineering through commissioning and reliability management. 15 years of working experience directly with Screw Pumps OEMs. Currently VP for the O&G operations of Leistritz Advanced Technologies Corp. Americas.

Introduction

- **Why?** End-user constant efforts in lowering the TCO and achieve ESG targets in their Heavy Oil Pipelines operations.
- **What?** The technology based on the standard API 676, sub-category Screw Pumps.
- **How?** Description of performance characteristics and design fundamentals, that enables effective deployment.
- **Where?** Typical applications of the technology and case studies.

Pipelines Overview

Pipelines: O&G facilities which main purpose is to transport the fluid **commodity or product from point A to B** with the **highest safety, lowest environmental impact and lowest total cost of ownership.**



Pipelines Overview

- ✓ **Commodity or product**: Preferer way to transport large volumes of Natural gas, crude oils or finish products.

- ✓ **Point A to B:** The product is normally transported between facilities that are physically and geography separated, which normally means long distances and elevation changes; this translate in higher operating discharge pressures for the pumping equipment.

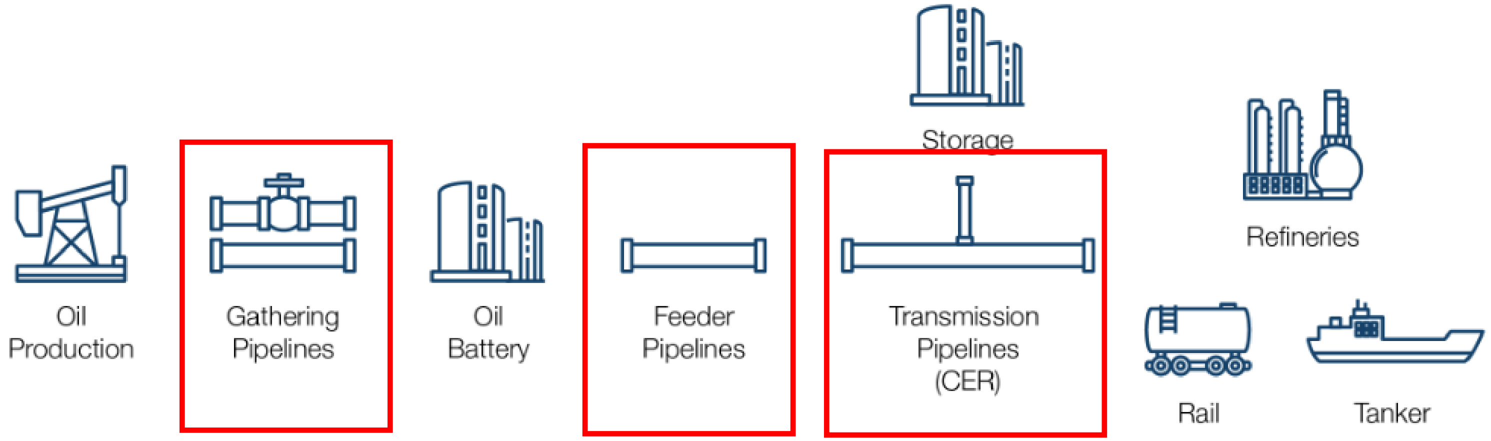
- ✓ **Safety and low environmental impact**: Safety and protection of personnel, communities and its environment is paramount, as pipelines cross towns, cities, provinces and countries; the facilities must comply with the highest standards of design and regulatory bodies requirements; adopting safe and efficient technologies with the lowest footprint.

- ✓ **Lowest total cost of ownership**: As OPEX far exceeds CAPEX in pipeline operations, Reliability and Energy Efficiency are normally the main drivers for a lower cost operation that increases returns to the shareholders and support ESG efforts.

Pipelines Overview

From Canada Energy Regulator:
Canada's crude oil pipeline network has three different types of pipelines:

Gathering pipelines	Move crude oil from the wellhead to storage and on to upgraders or refineries. Provincial regulators typically regulate these facilities.
Feeder pipelines	Transport crude oil from storage tanks and processing facilities to transmission pipelines. Provincial regulators typically regulate these facilities.
Transmission pipelines	Transport crude oil to refining markets, often across provincial or international boundaries. Transmission pipelines are typically regulated by the CER.



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Screw Pumps

Key components of **liquid pipeline facilities are pumps**, which provides the necessary energy to the product confined in the duct/pipe to move it from point A to B, at the required flow rate and pressure.

Common pump technologies used in pipelines operations are:

- Centrifugal pumps; Rotodynamic Family
- Plunger pumps; Reciprocating Family

From Rotary Positive Displacement Family

- Gear pumps
- **Screw Pumps (Commonly used in heavy crude oil gathering and feeders' pipelines)**

Screw Pumps

Rotary Positive Displacement Pumps – Classification

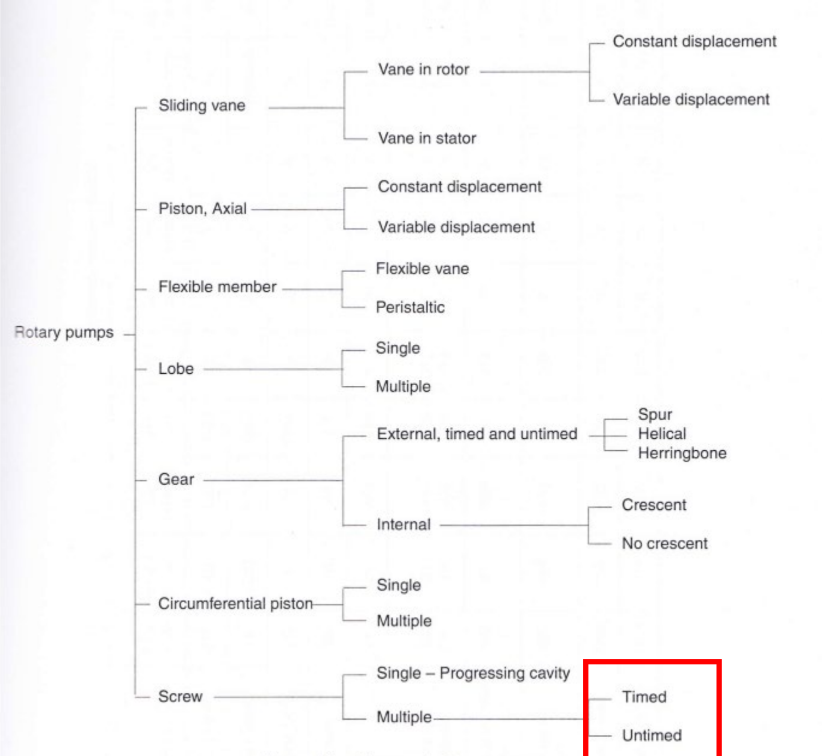


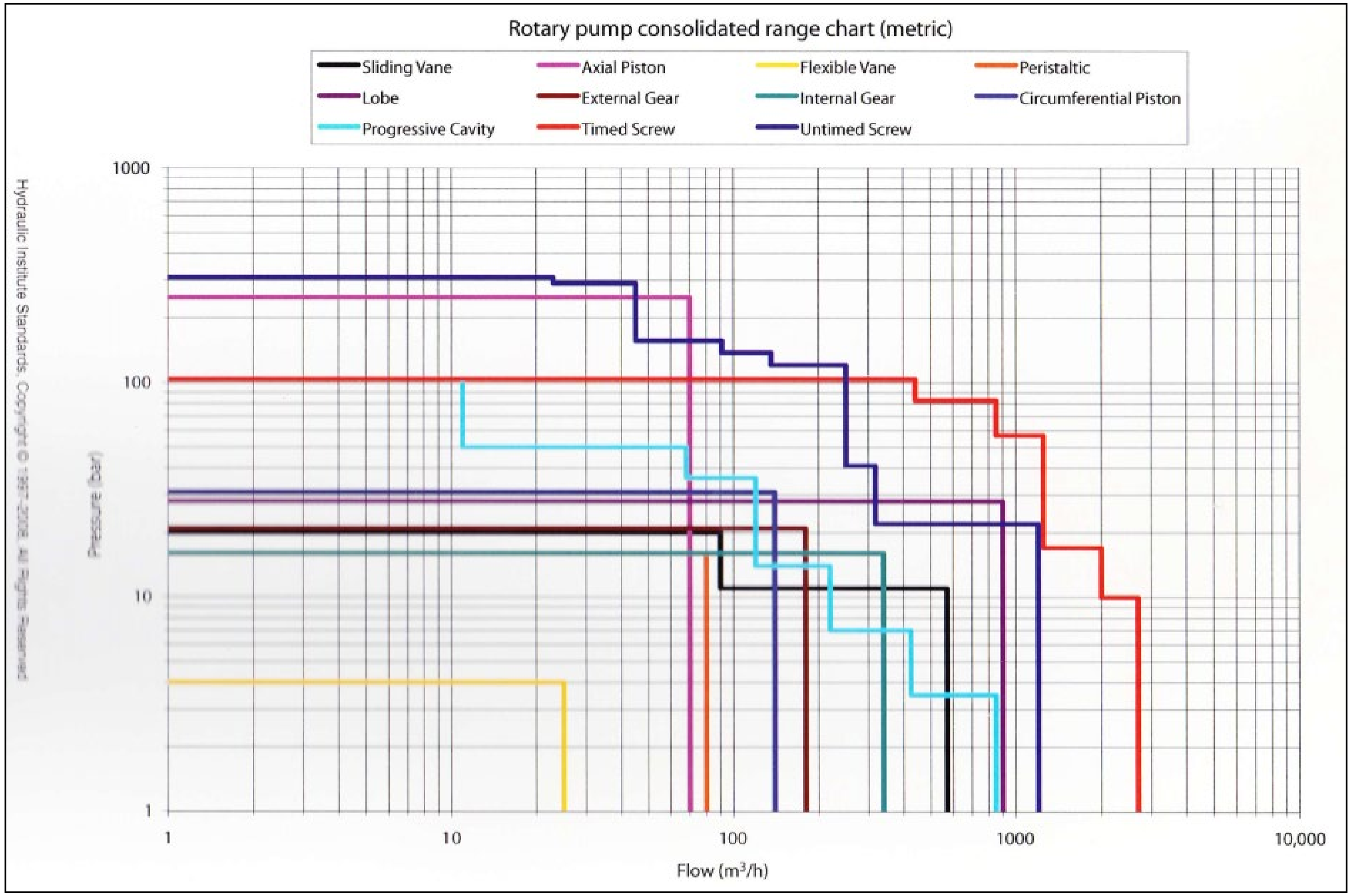
Figure 3.1 — Types of rotary pumps

Capability table – Metric

Pump type	Flow m^3/h	Pressure *bar*	Viscosity *cSt* (×1000)	Solids *cm*	Temps. °C	Dry, Self-priming	Wet, Self-priming	Dry running	Reversible	Abrasive handling	Shear sensitive	Pulseless	Power *kW*
Sliding vane	570	20	220	0.08	200	Y	Y	Y	Y	Fair	Fair	Fair	0.75-190
Piston, axial	70	250	0.44	Clear	60	N	Y	Y	Y (special)	Poor	Poor	Poor	0.75-450
Flexible vane	25	4	22	Clear	90	Y	Y	N	N	Fair	Good	Good	0.15-4
Peristaltic	80	16	44	3.3	80	Y	Y	Y	Y	Excellent	Excellent	Poor	0.1-30
Lobe	900	28	440	6.35	177	N	Y	Y	Y	Good	Excellent	Fair	0.75-160
Gear,													
external	180	21	440	0.08	275	Y	Y	Y	Y	Good	Good	Good	0.37-110
internal	340	16	440	0.08	275	Y	Y	N	Y	Good	Good	Good	0.37-110
Circumferential piston	140	31	1000	3.2	275	Y	Y	Y	Y	Good	Excellent	Poor	0.75-150
Progressing cavity	850	104	440	9	205	Y	Y	N	Y	Excellent	Excellent	Excellent	0.1-150
Timed screw	2700	104	990	0.08	320	N	Y	Y	Y	Good	Good	Excellent	3.7-1500
Untimed screw	1200	310	220	Clear	275	N	Y	N	Y (special)	Good	Good	Excellent	0.75-750

Courtesy of the Hydraulic Institute, pumps.org

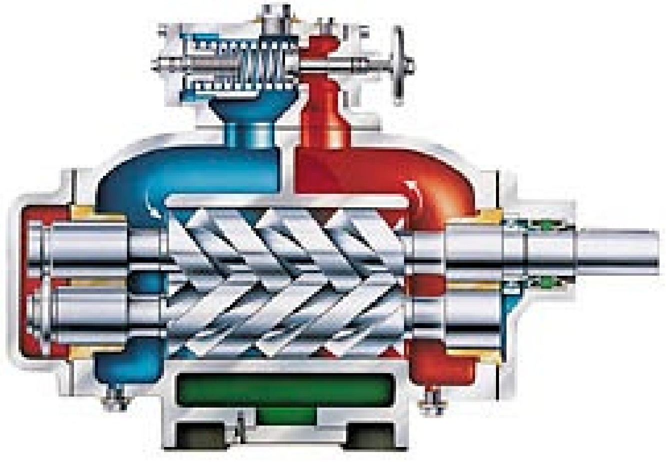
Rotary Positive Displacement Pumps – Classification



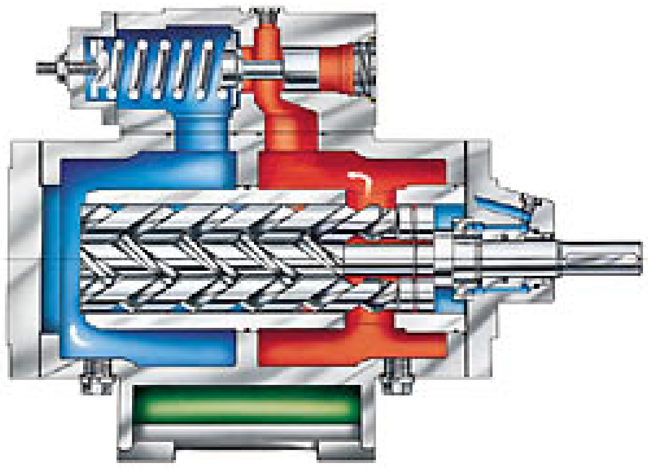
Courtesy of the Hydraulic Institute, pumps.org

Screw Pumps

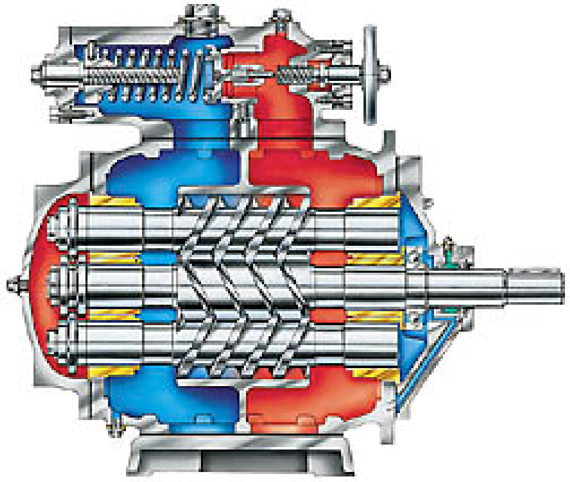
Untimed Screw Pumps – Rely on **the hydrodynamic film** to transmit rotation from the power screw to the idler screw/s. Internal running clearances are process dependent.



Two (2) screw pumps



Three (3) screw pumps



Five (5) screw pumps

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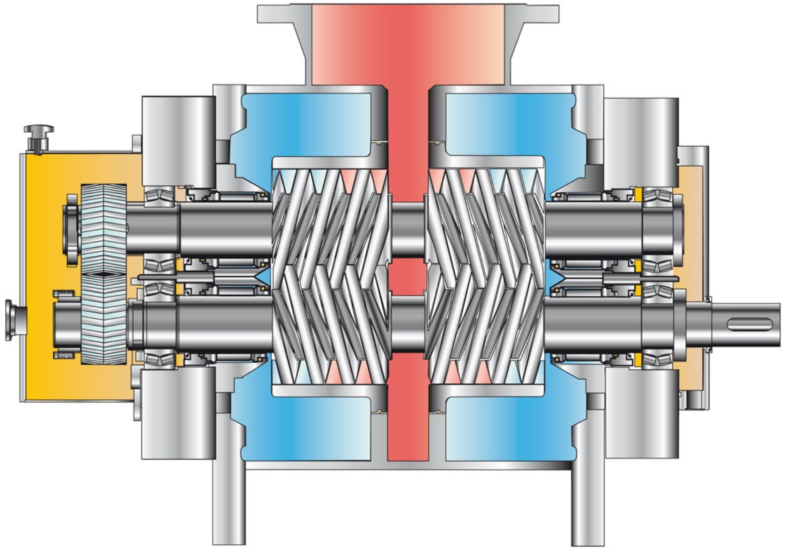
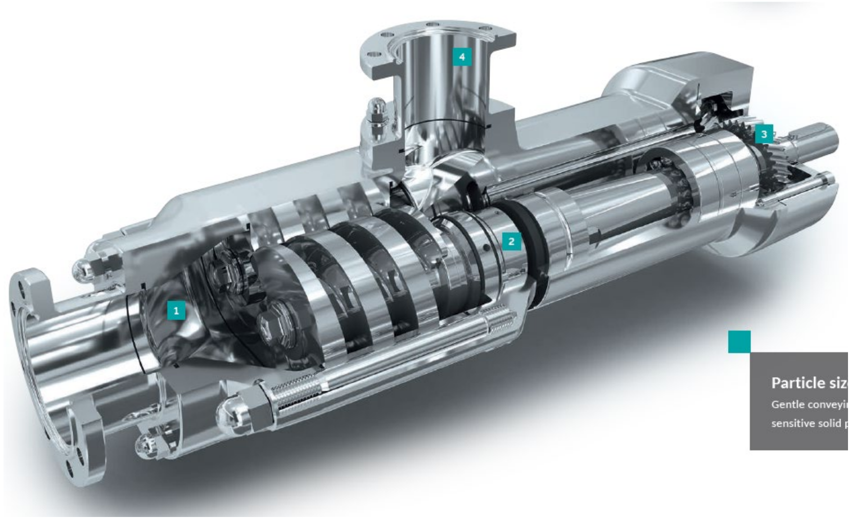
Screw Pumps

Timed Screw Pumps – Transmit the rotation from the Driver Screw to the Driven Screw via **external timing gears;** internal running clearances are mechanically fixed.



Four (4) screw / twin screw, between bearings type.



Twin screw, overhung type.

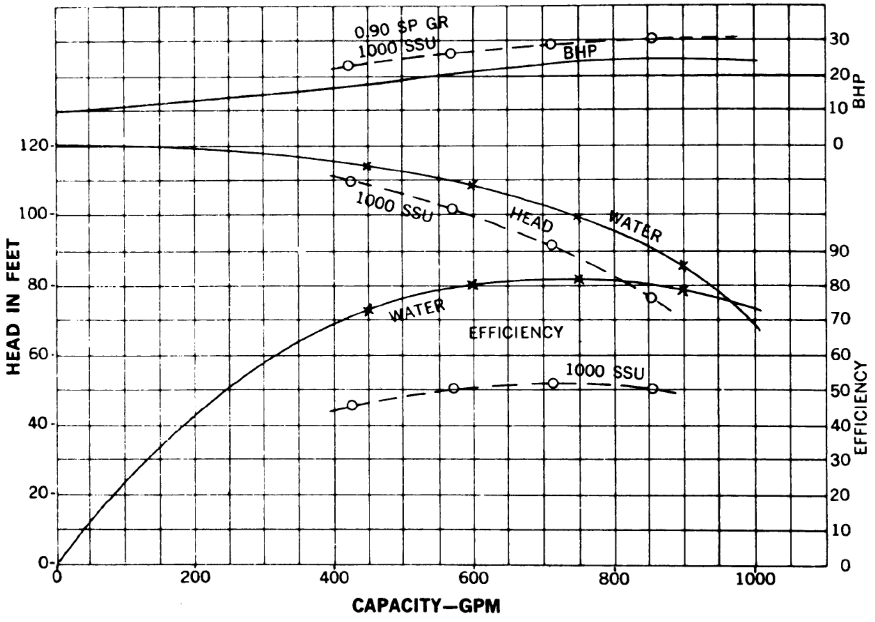
Courtesy of the Hydraulic Institute, pumps.org

Performance

Screw Pumps support energy efficient Heavy Oil Pipeline operations

Typical performance impact in centrifugal pumps as product viscosity increases

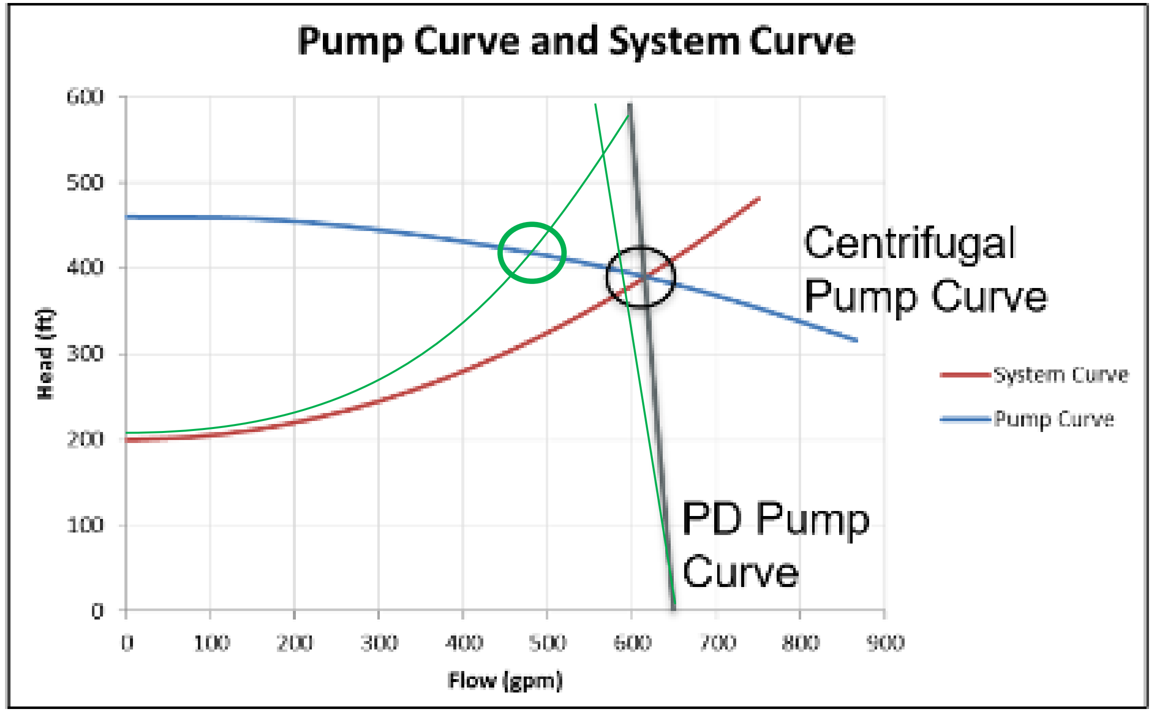
Viscosity (SSU)	100	250	500	750	1000
Flow reduction (percent)	3	8	14	19	23
Head reduction (ft. percent)	2	5	11	14	18
Power increase (Percent)	10	20	30	50	65



Courtesy of the Hydraulic Institute, pumps.org

Performance

Screw Pumps support energy efficient Heavy Oil Pipeline operations



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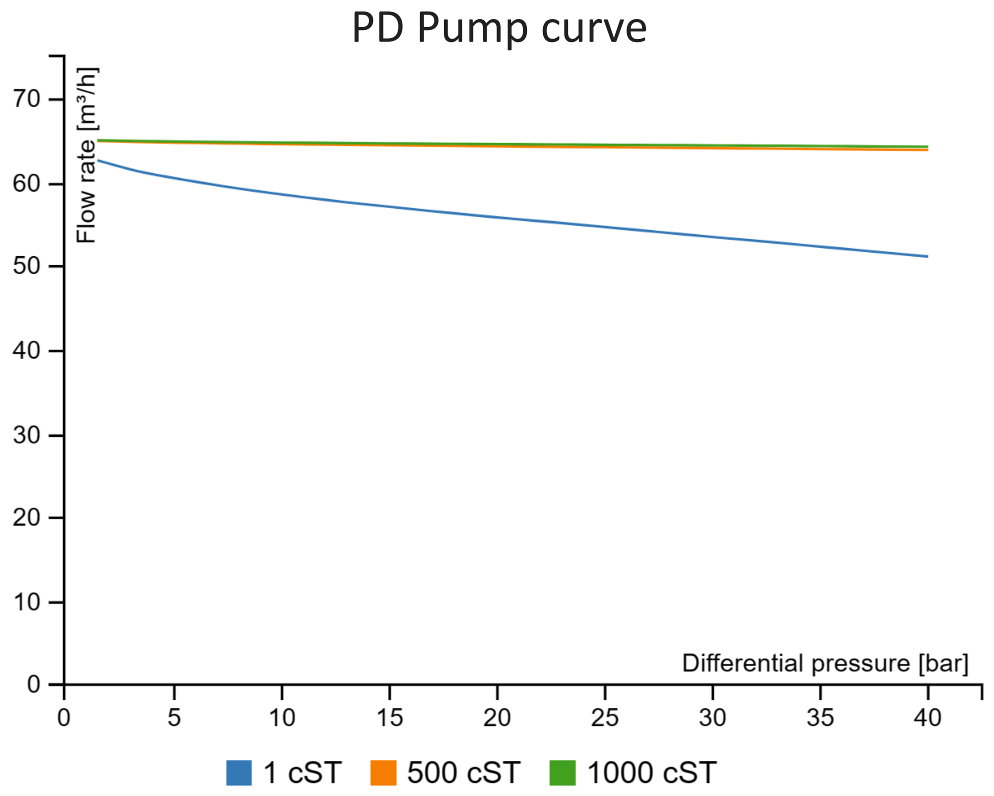

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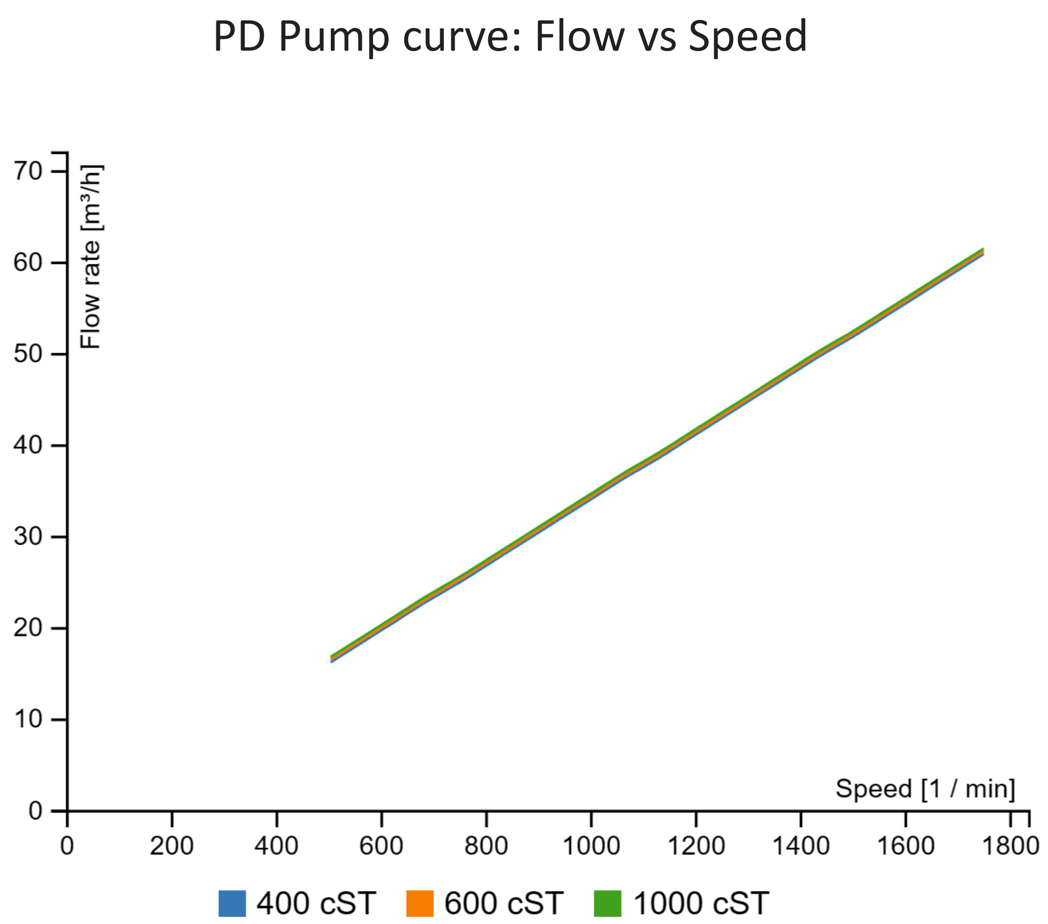
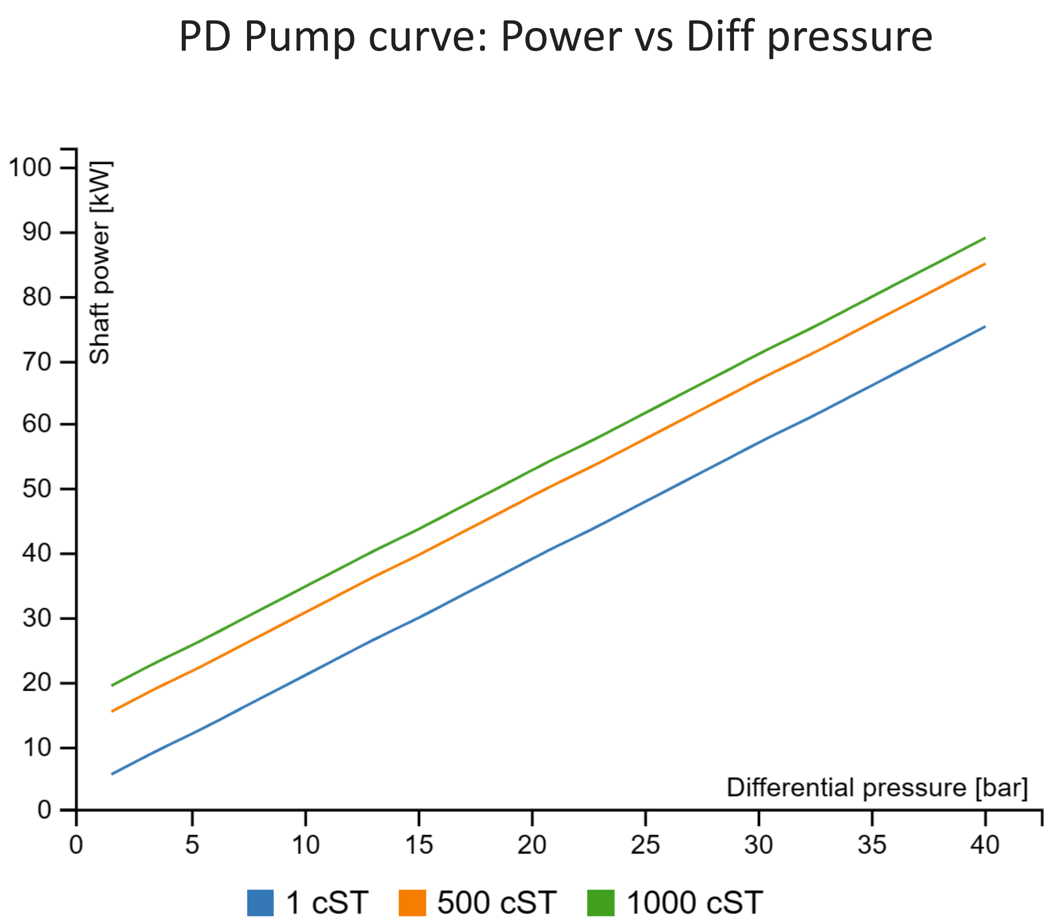
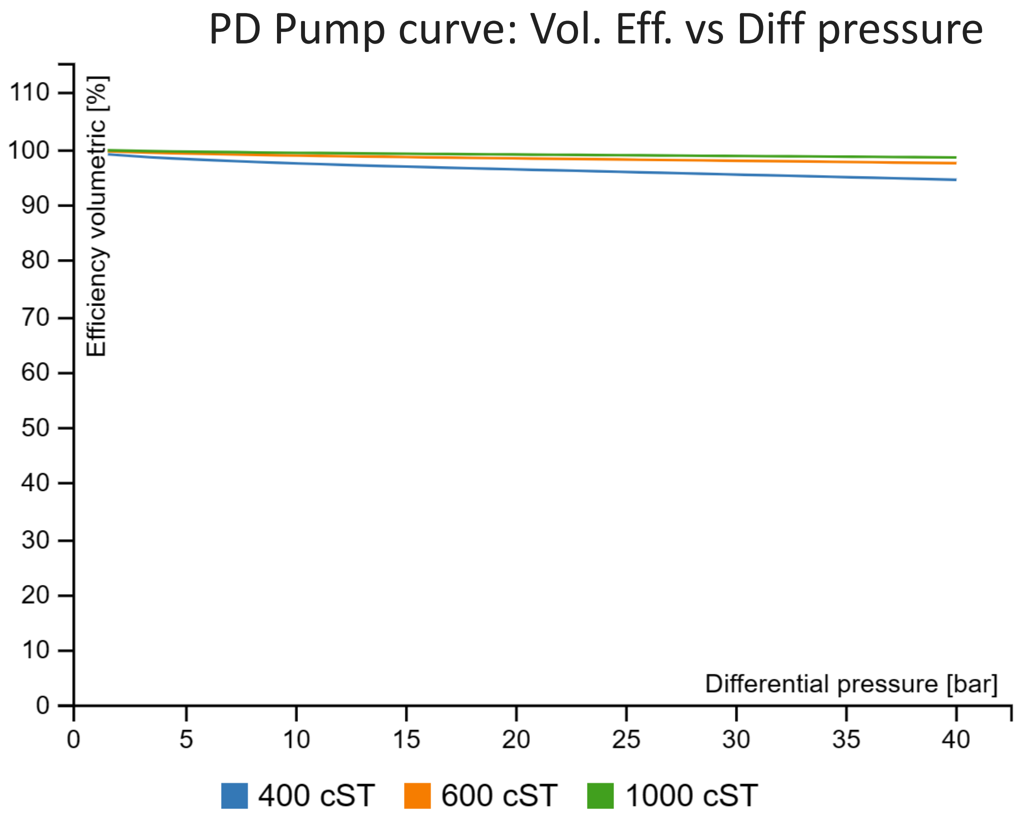
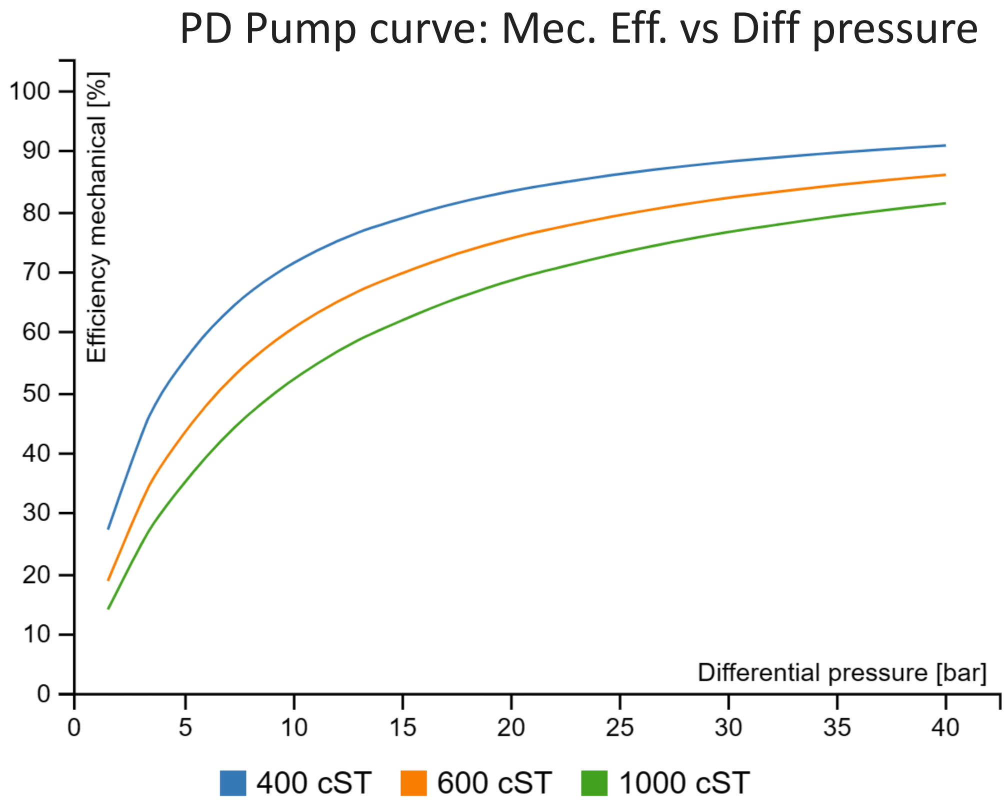
Performance





Performance





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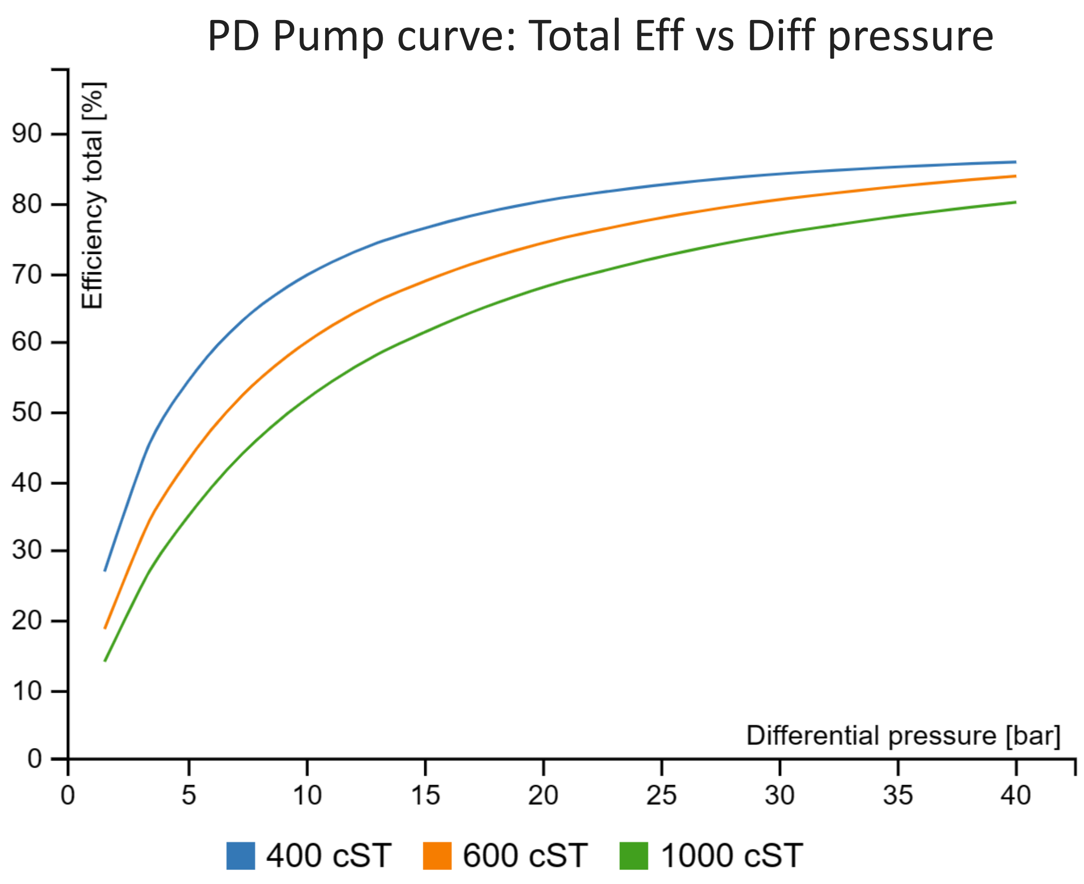
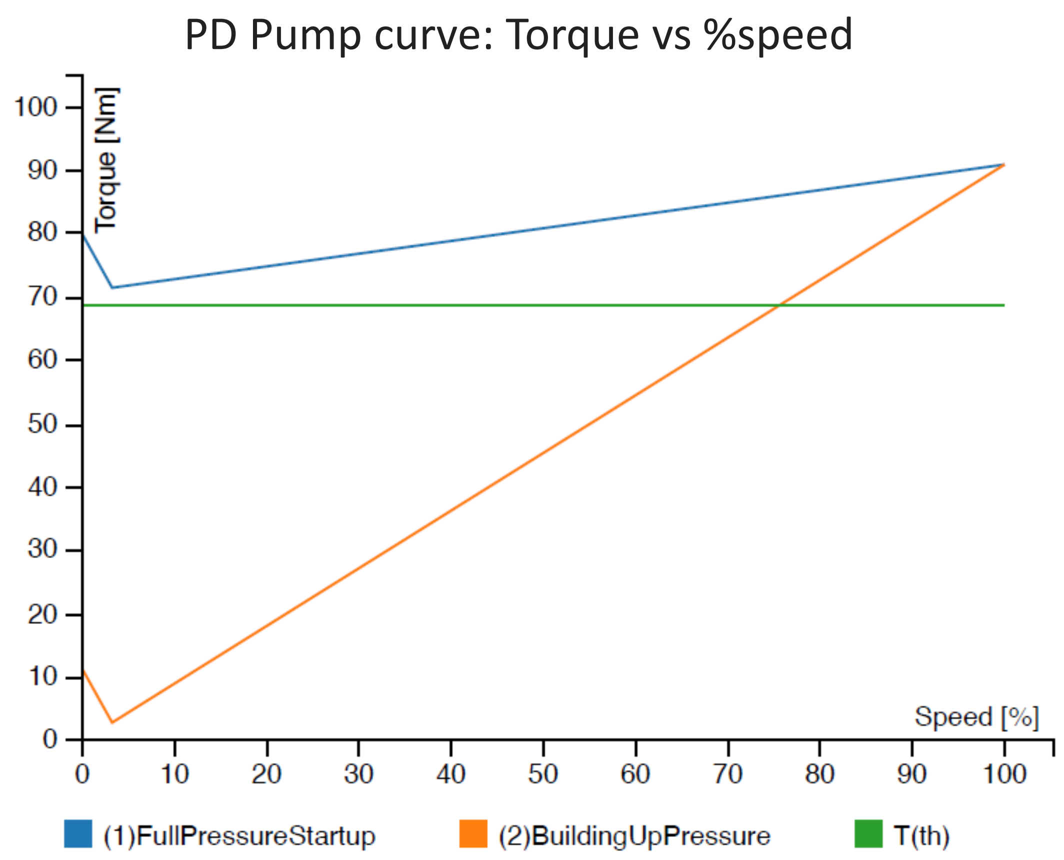
Performance





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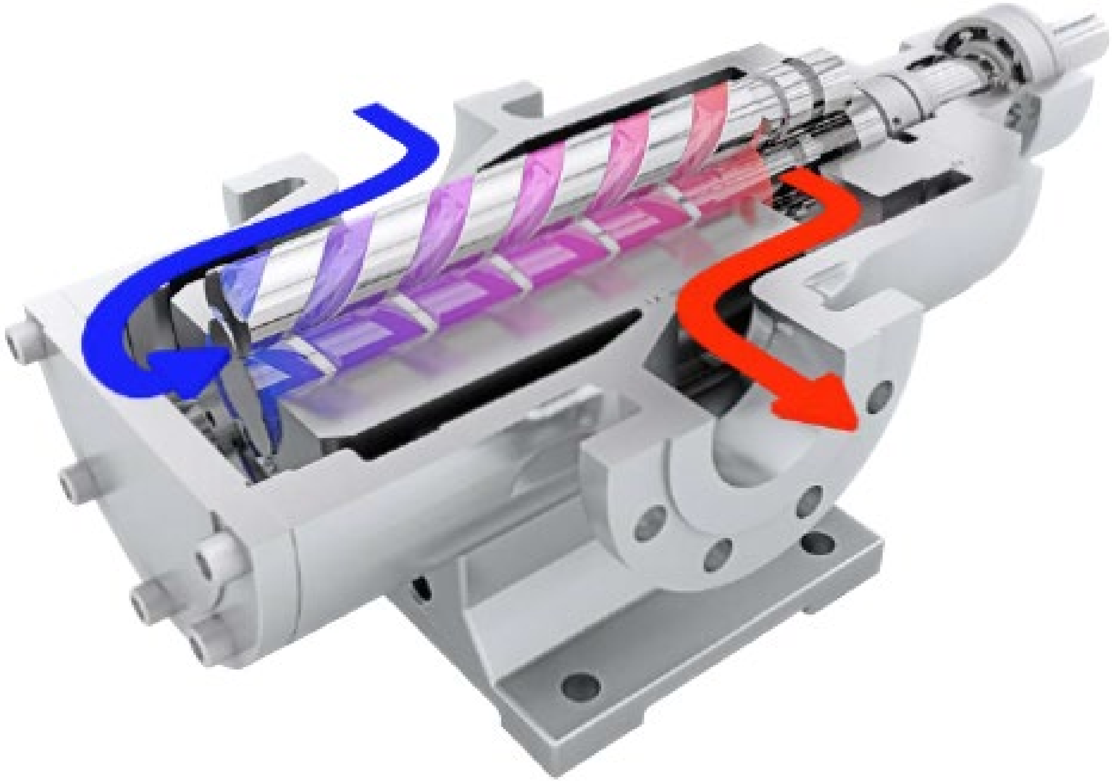
Performance

Over performance characteristics of Screw Pumps:

- Smooth low pulsation operation
- Lower NPHS requirement, low internal velocity
- Constant flow rate; low sensitivity to changes in product viscosity and down stream pressure
- Flow rate directly proportional to rotational speed
- Direct drive, no need for gear boxes/reducers
- High tolerance to entrain gas
- Low shear operation

Design Fundamentals (Untimed)



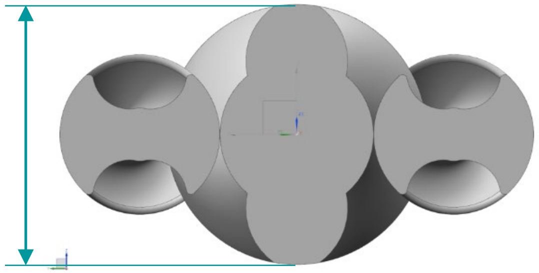
Design Fundamentals (Untimed)

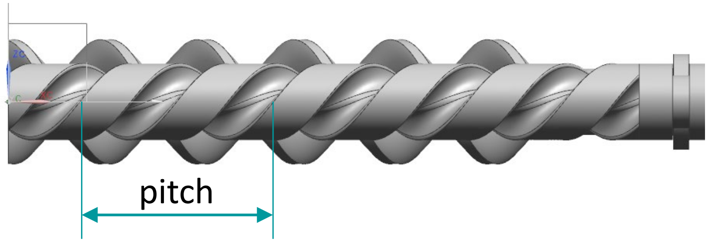
Flow rate

$Q = Q_{th} - Q_{Leakage}$

Theoretical flow:

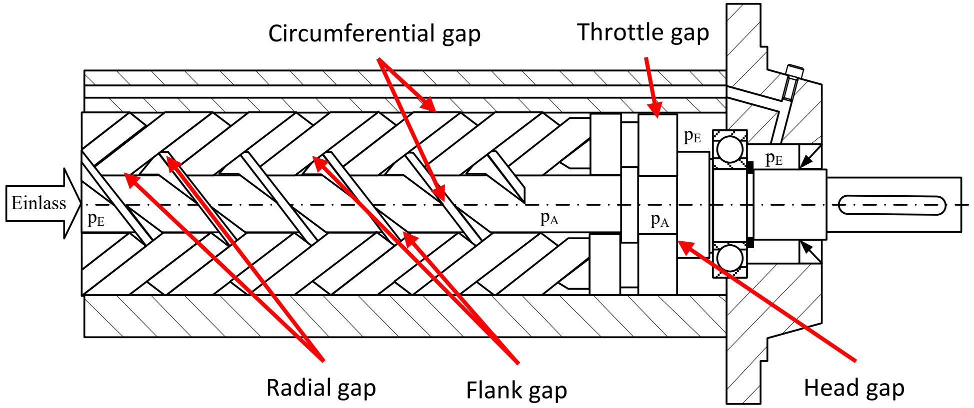
Q_{th} = f(type, size, pitch, speed)





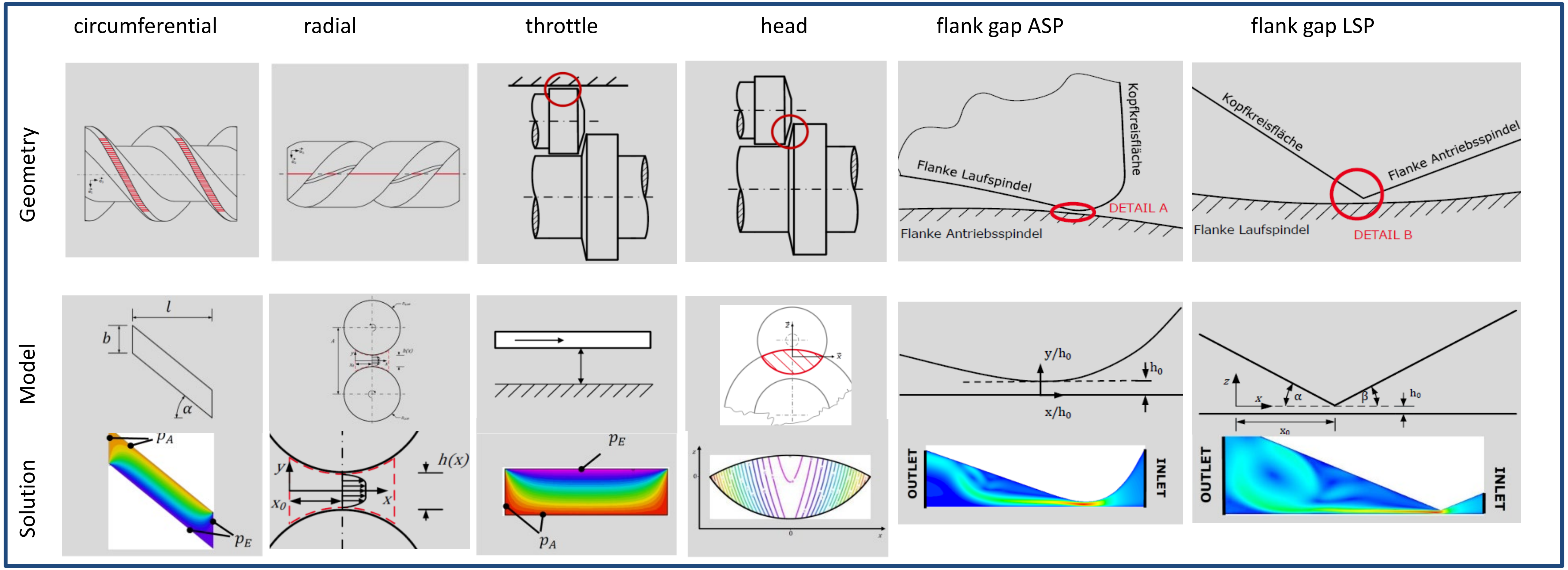
Leakage flow:

$Q_{leakage}$ = f(pressure, vicosity, speed, gaps)



Design Fundamentals (Untimed)

Clearances



- No CFD necessary
- Analytical models for each gap available

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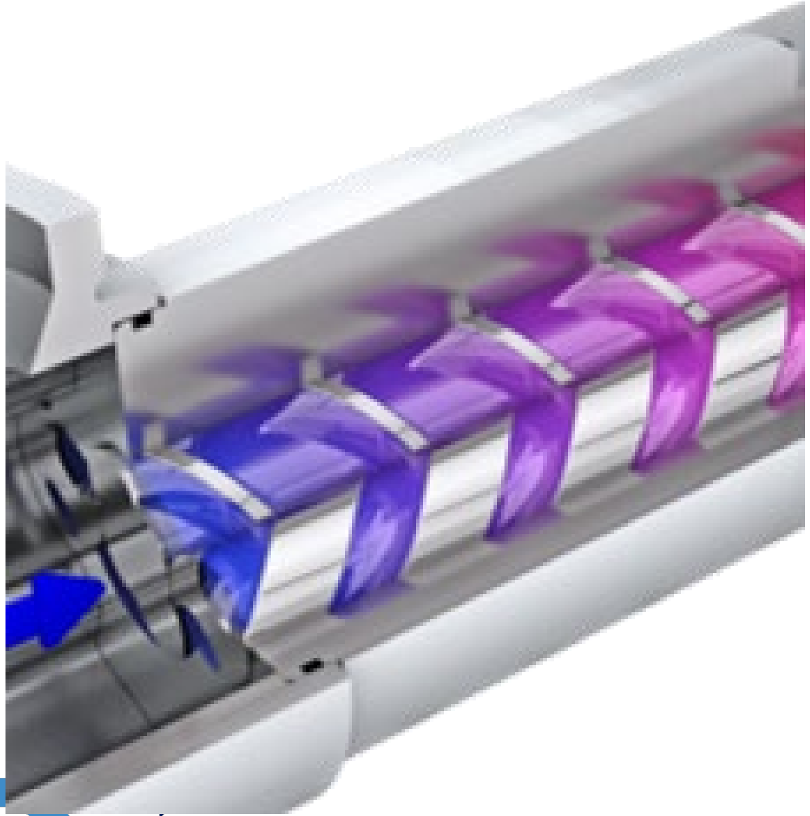
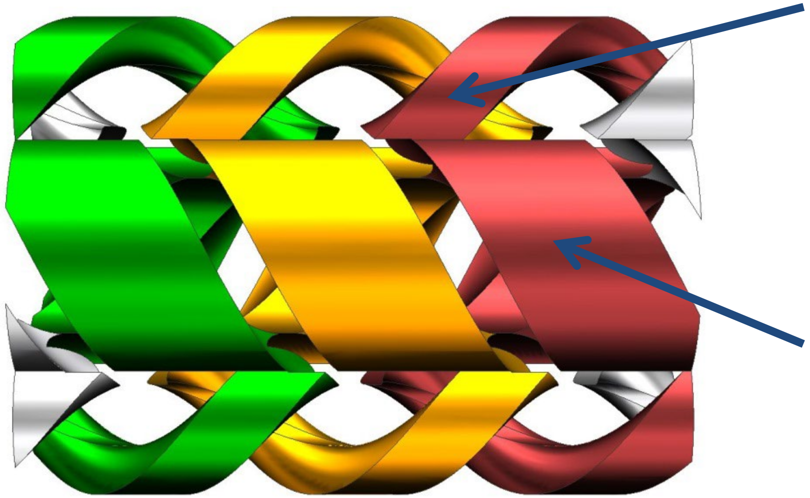
Design Fundamentals (Untimed)

Chambers



Picture shows a pump in operation where all metal parts are faded out → only the fluid inside of the rotor chamber remains (same color = same chamber = same pressure)

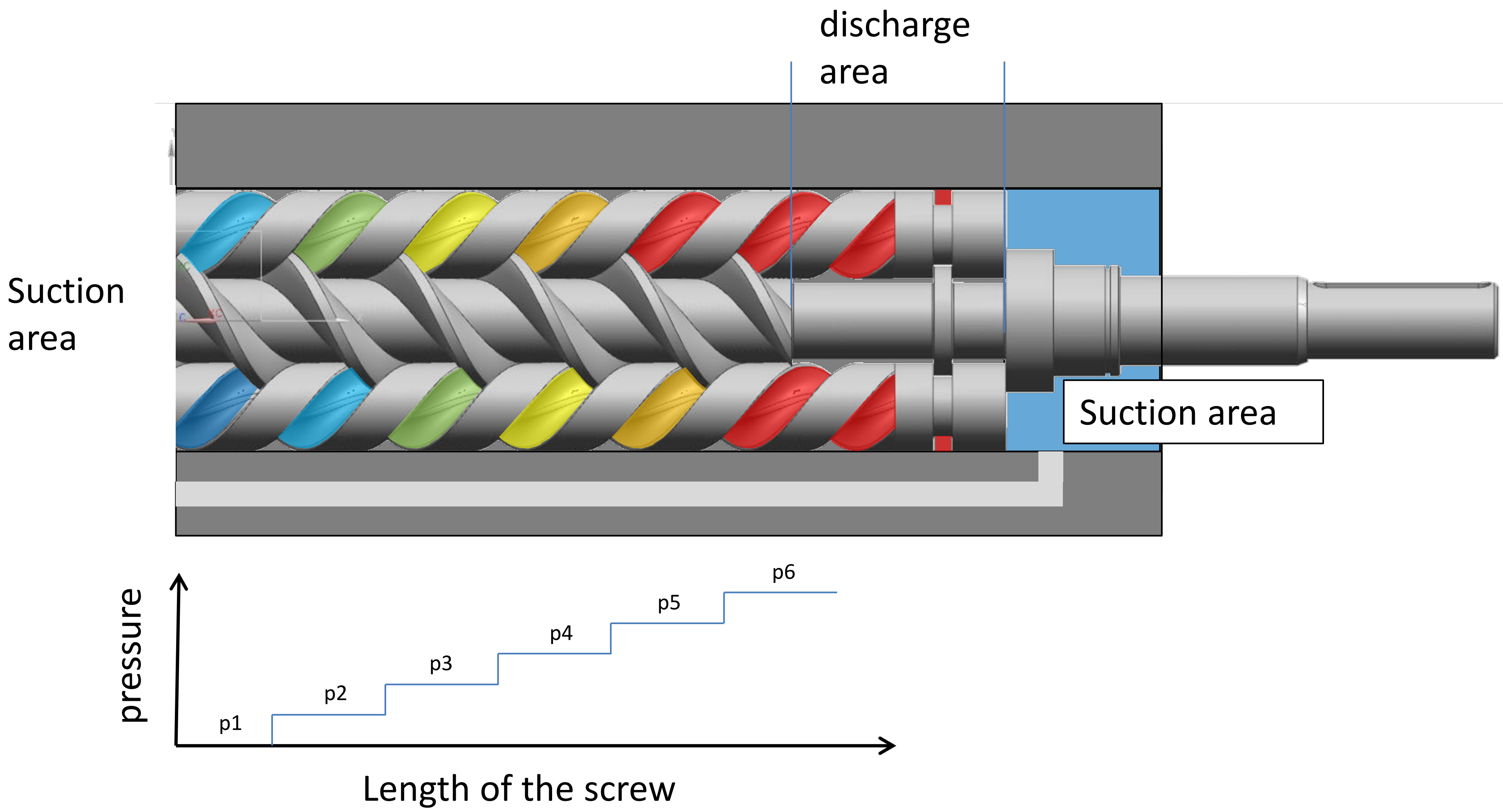


LSP: chamber of higher pressure is located above chamber with lower pressure → radial forces on the idler

ASP: Chamber with same pressure opposite of each other → no radial force on driving screw

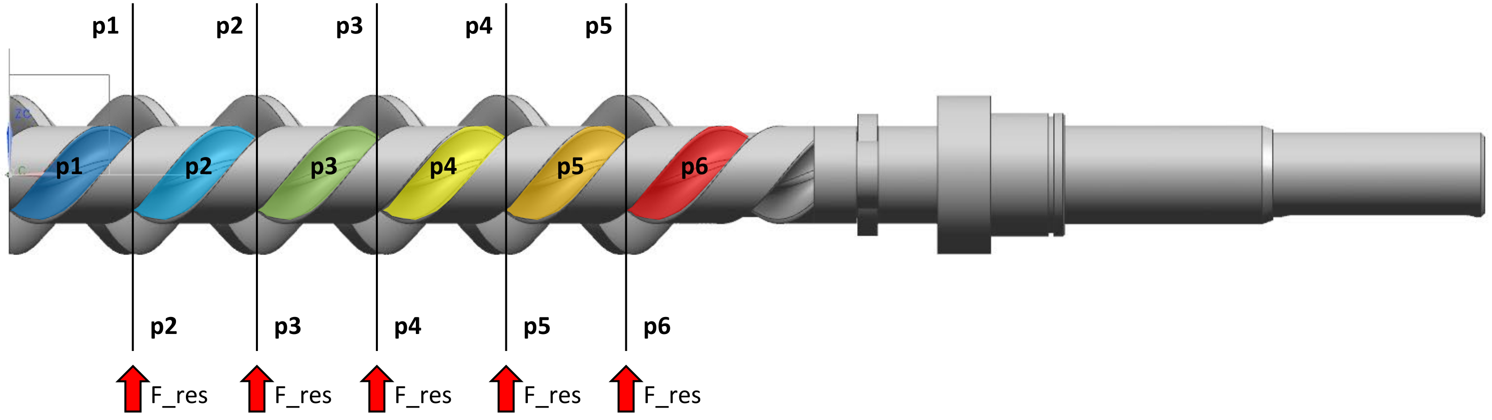
Design Fundamentals (Untimed)

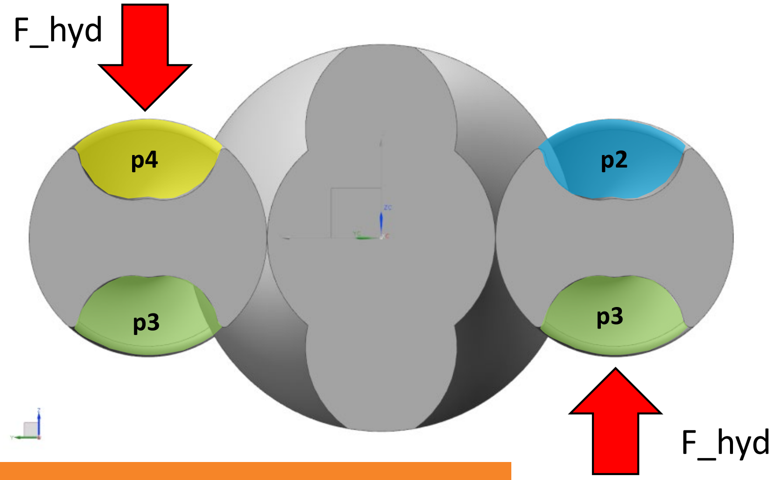
Pressure distribution



Design Fundamentals (Untimed)

Resulting radial load

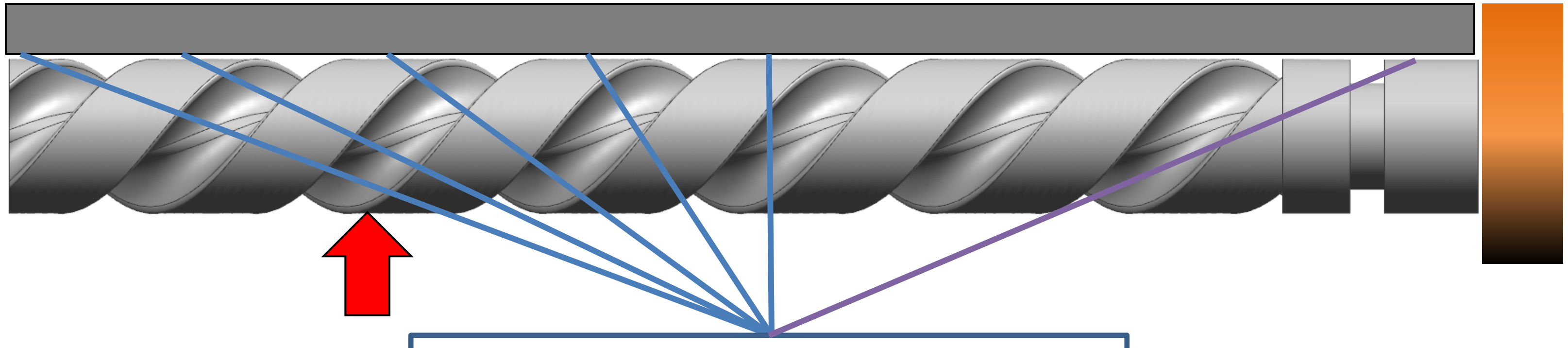




Diving spindle is hyd. balanced.

Design Fundamentals (Untimed)

Hydrodynamic sleeve bearing system



$$\frac{\partial}{\partial x}\left(\frac{h(x)^3}{12\mu}\frac{\partial p}{\partial x}\right)+\frac{\partial}{\partial z}\left(\frac{h(x)^3}{12\mu}\frac{\partial p}{\partial z}\right)=\frac{\partial\left(h(x)U\right)}{\partial x}$$

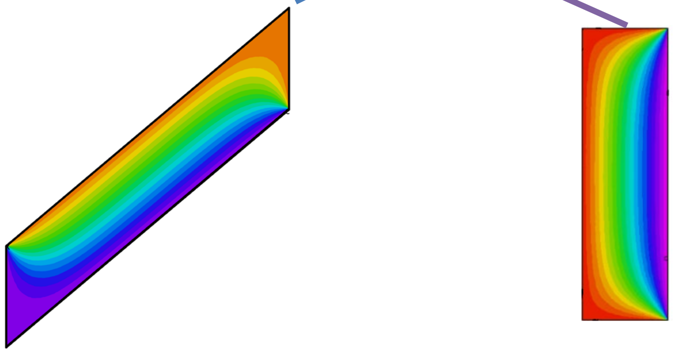
Reynold differential equation for fluid films

Dependence:

↗ Viscosity

↗ Differential pressure

↗ Speed

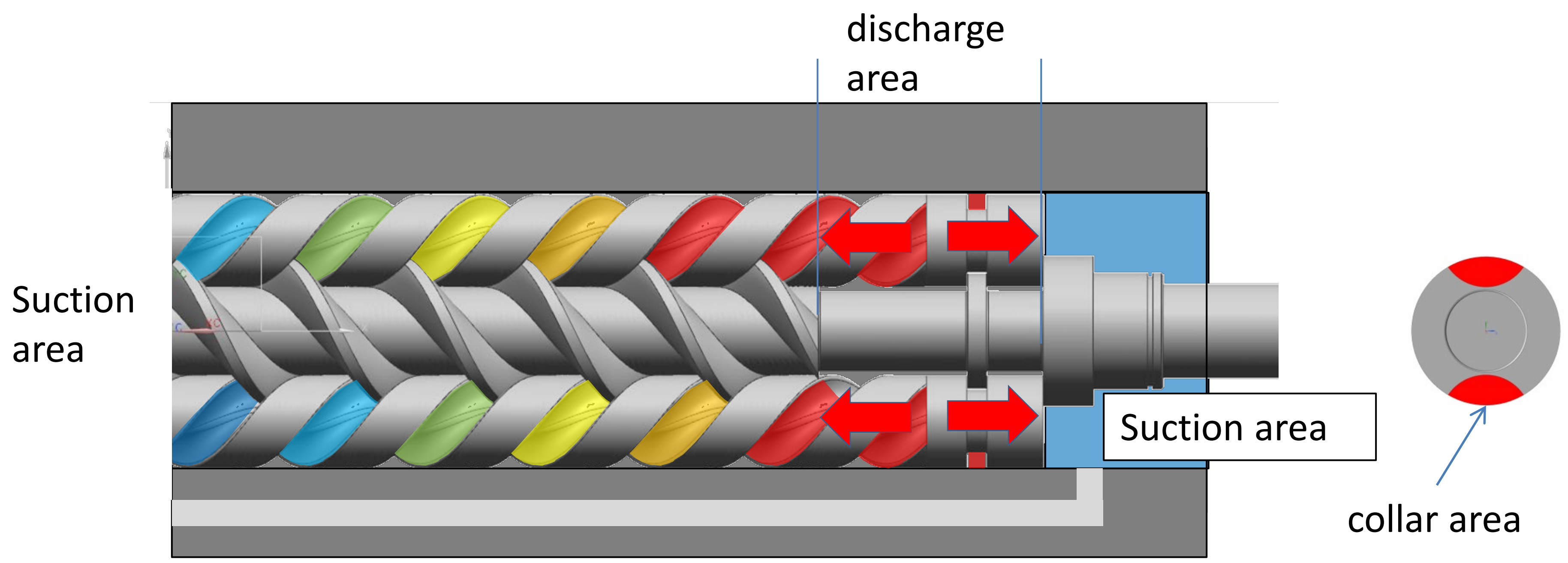


Pressure distribution in the journal bearings of the pump

➡ **Height of the fluid film**

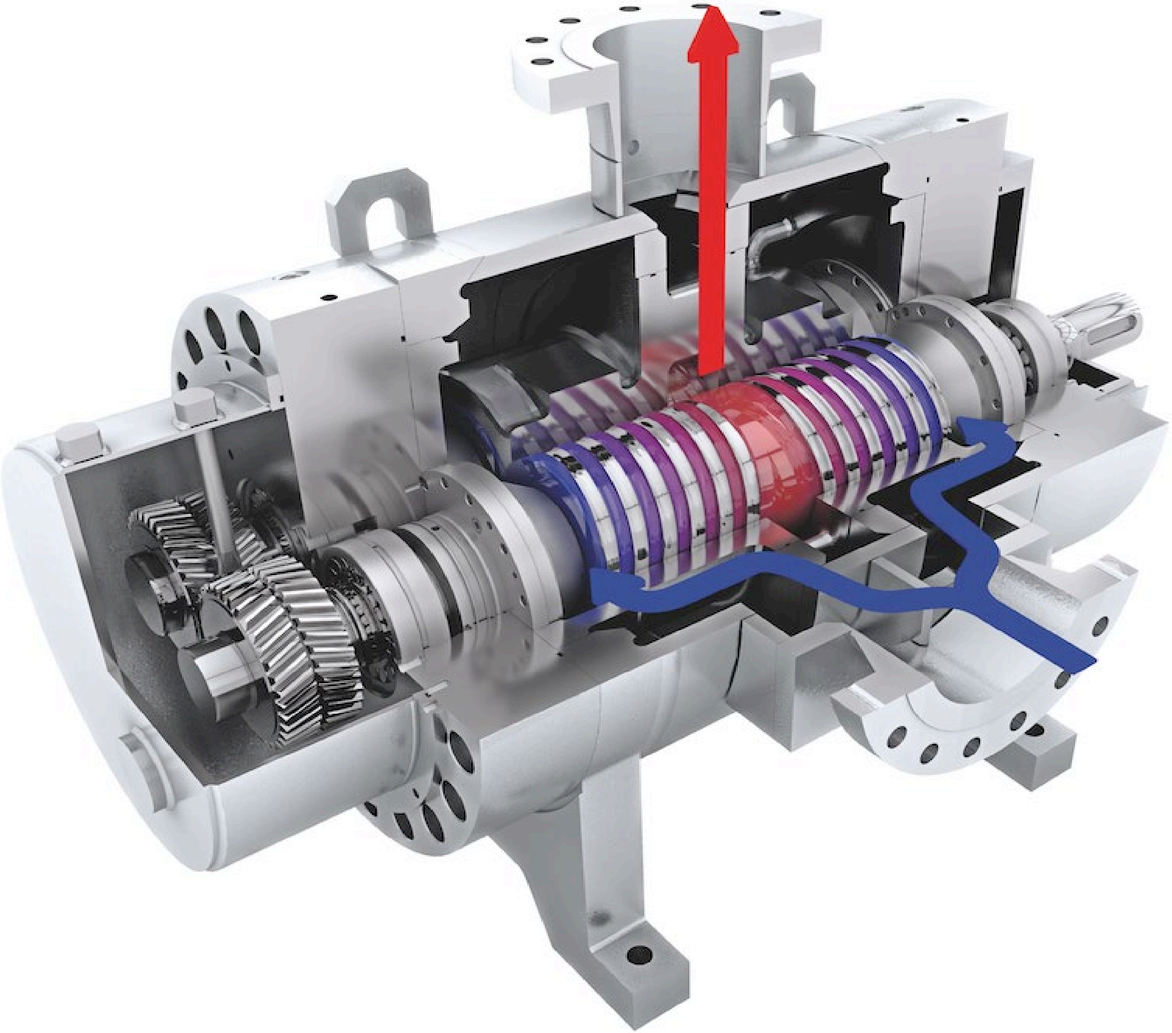
Design Fundamentals (Untimed)

Thrust loads



The axial thrust is nearly compensated. The pressurized areas are similar. The remaining thrust load will be handled by the collar between driving an driven spindle.

Design Fundamentals (Timed)



Design Fundamentals (Timed)

RADIAL HYDRAULIC LOAD ON ROTORS

Average Hydraulic Load on Profile Package

F = 0.5 * dp * Da * T * m

whereas

dp	Differential Pressure
Da	Outer Rotor Diameter
T	Profile Pitch
m	Rotor centerline distance/ outer rotor diameter

→ Radial Hydraulic Load on Pump Rotors

directly proportional to Differential Pressure

Design Fundamentals (Timed)

SHAFT DEFLECTION UNDER LOAD

Simplified Shaft Deflection

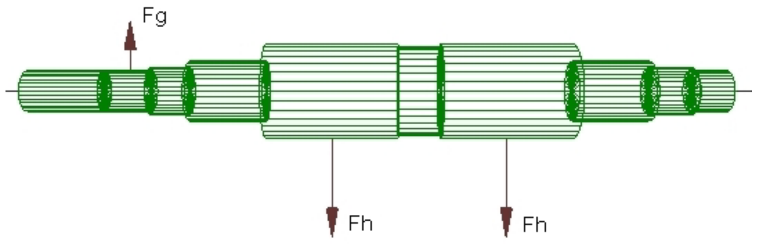
$$S = K * F * l^3 / D^4$$

with

F	Radial Hydraulic Load
l	Bearing Span
D	Shaft Diameter
K	Design Constant

More detailed load model uses:

- Hydraulic Radial Load
- Gear Reaction Load



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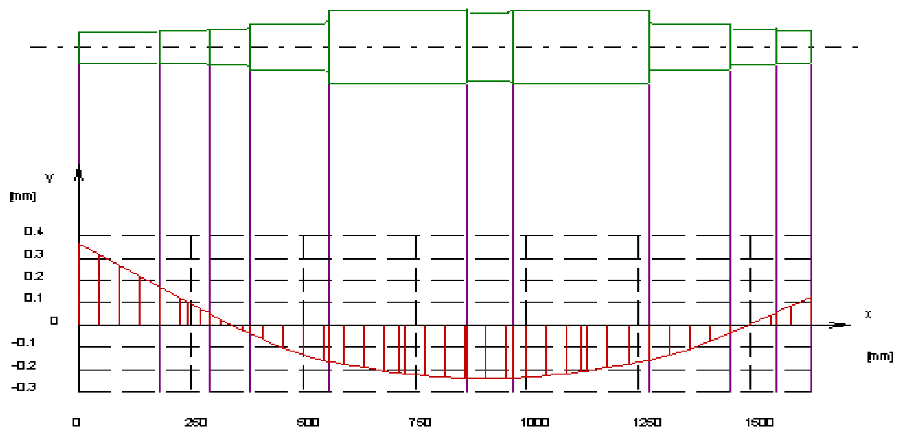
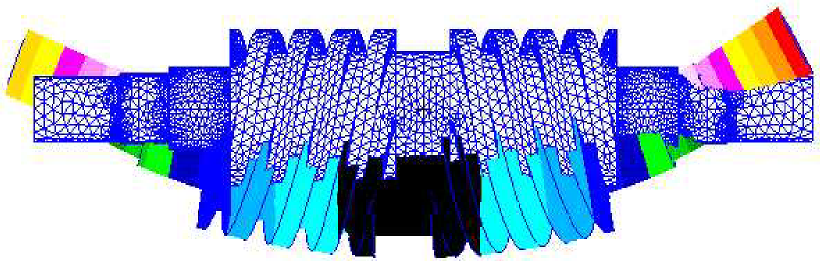




Design Fundamentals (Timed)

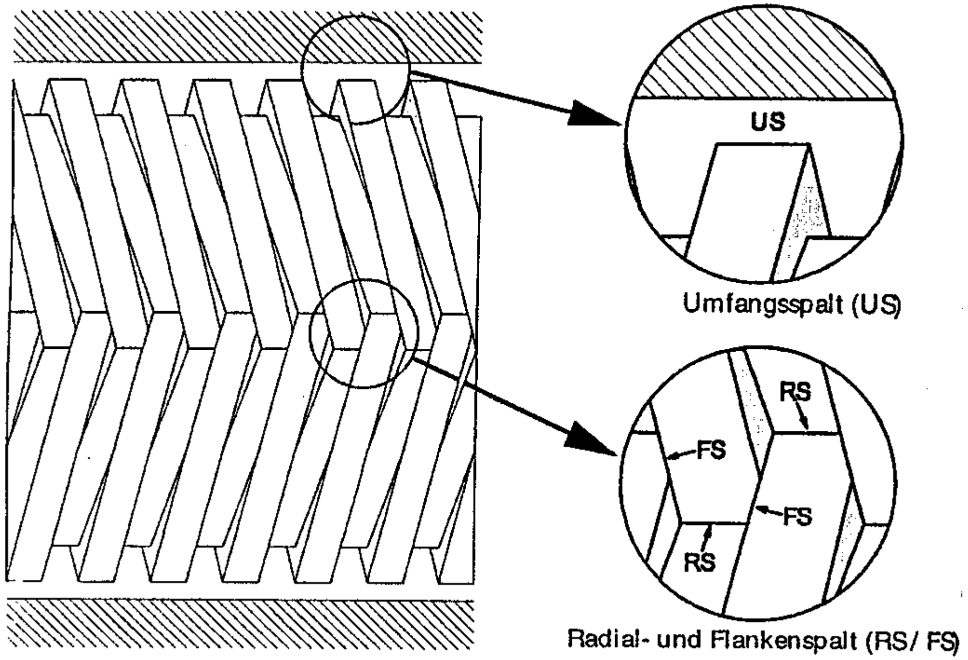
INTERNAL CLEARANCES AND SLIPPAGE
Internal Clearances defined by:

- Design Clearance (nominal)
- Machining Tolerances
- Tolerance Stack-Up (68% acc. Gauss)
- Shaft Deflection
- Thermal Growth due to Compression Heat (MPP only)
- Minimum remaining Clearance (typically 100 micron)

For laminar flow the slippage is proportional to the differential pressure. This reduces hydraulic efficiency !

<u>Counter measures:</u>

- Reduced internal clearances
- Increased number of pumping locks
- Increased axial length of rotor tips



Design Fundamentals (Timed)

BEARING LOADS

Radial Bearings:

- Spherical or conical roller bearings
- Tapered roller bearings for large size pumps
- Bearing life calculation acc. DIN ISO 281
- No thrust bearing required due to double flow arrangement
- 10h – lifetime minimum 25,000h (Design)
- Oil lubricated (splash or forced)
- No hydrodynamic fluid film between rotors and casing - MPP

Example	Bearing Load		L10-Bearing Life	
Drive Shaft, NDE	51022	N	61168	h
Drive Shaft, DE	76042	N	28126	h
Driven Shaft, NDE	97372	N	34997	h
Driven Shaft, DE	72352	N	33224	h

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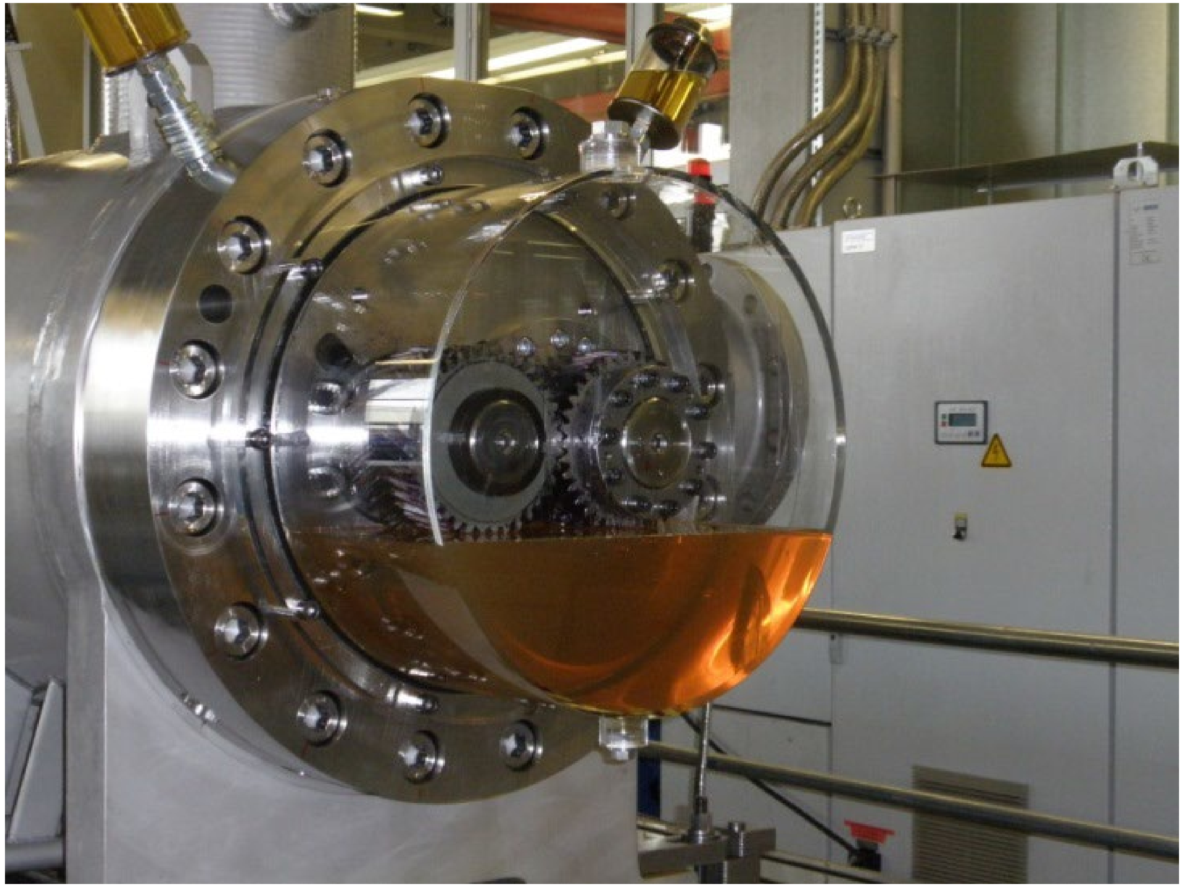
Design Fundamentals (Timed)

Timing Gears

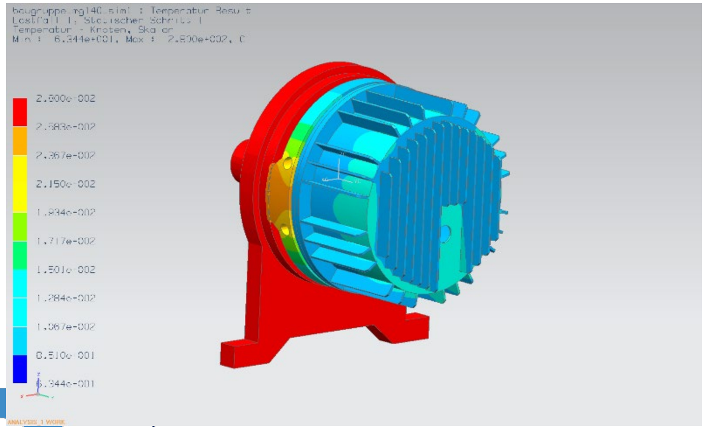
- Overhung gear box design
- Shaft deflection considered
- (Crowning if required)
- Made from case hardened steel
- Designed acc.DIN 3990 B
- Located on the NDE
- Oil lubricated, splash or forced
- Adjustable during assembly

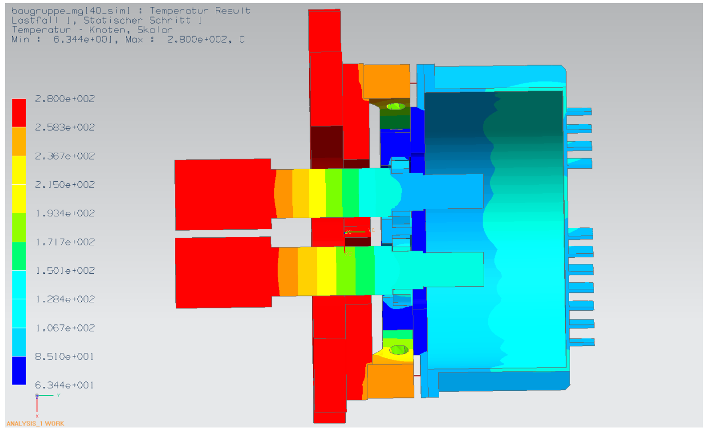


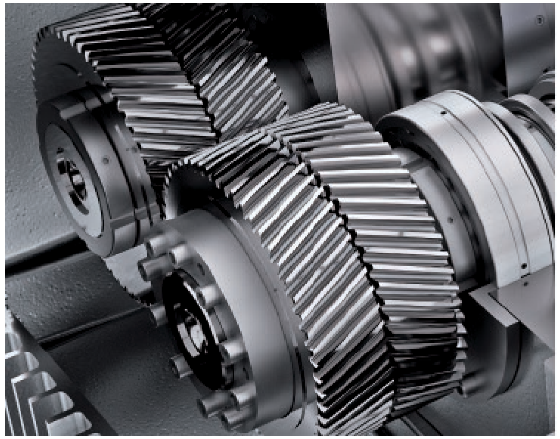
Design Fundamentals (Timed)

COOLING REQUIREMENTS

- Maintain max. Bearing Temperature at 100°C
- Decision if forced lube oil system is required based on
  - fluid temperature
  - Input power
  - Site conditions
- Definition of cooling requirements based on field verified theoretical models and in-house testing



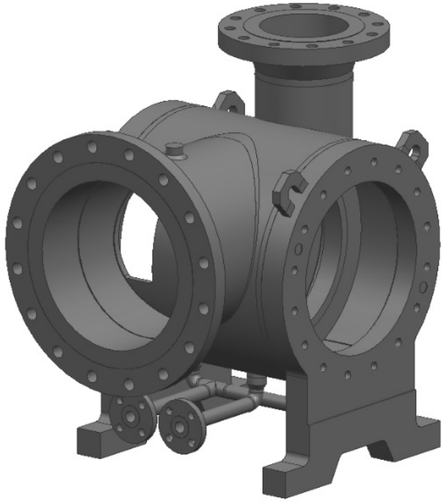


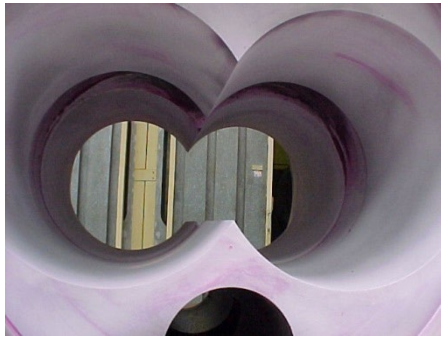


Design Fundamentals (Timed)

CASING DESIGN

- Acc. AD-Merkblätter (German Pressure Vessle Code)
- Standard Corrosion allowance 3mm
- API 676 flange loading





Design Fundamentals (Timed)

Mechanical Seals

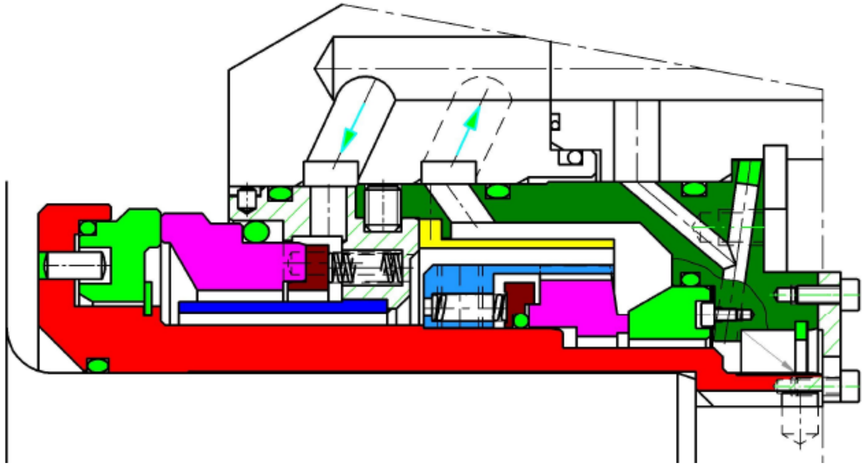
- Exposed to suction pressure only
- Mainly Cartridge design for easy maintenance

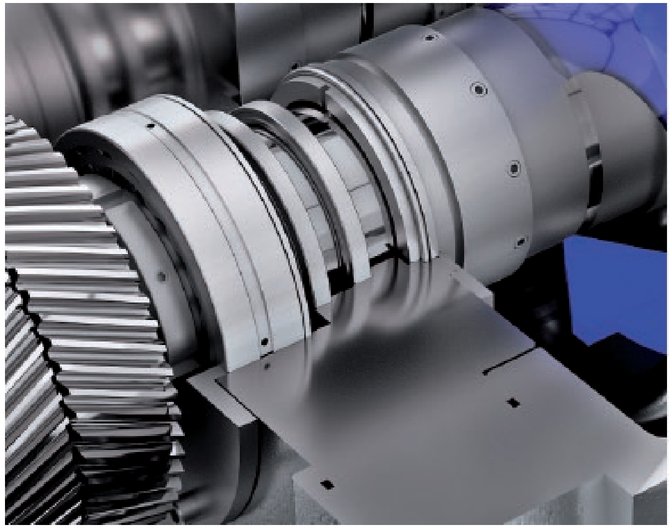
Types

- Single acting
- Single acting with throat bushing
- Both optional with pressureless quench

Double acting with external pressurize flush API seal plan guarantees the highest MBTF for:

- GVF's up to 100%
- High sand content
- Slug Flow
- Sour Gas Service





Case Study

Case Study 1: Internal/Feeder Pipeline Booster - Comparative Analysis BB3 vs 3 Screw Pump (Colombia)

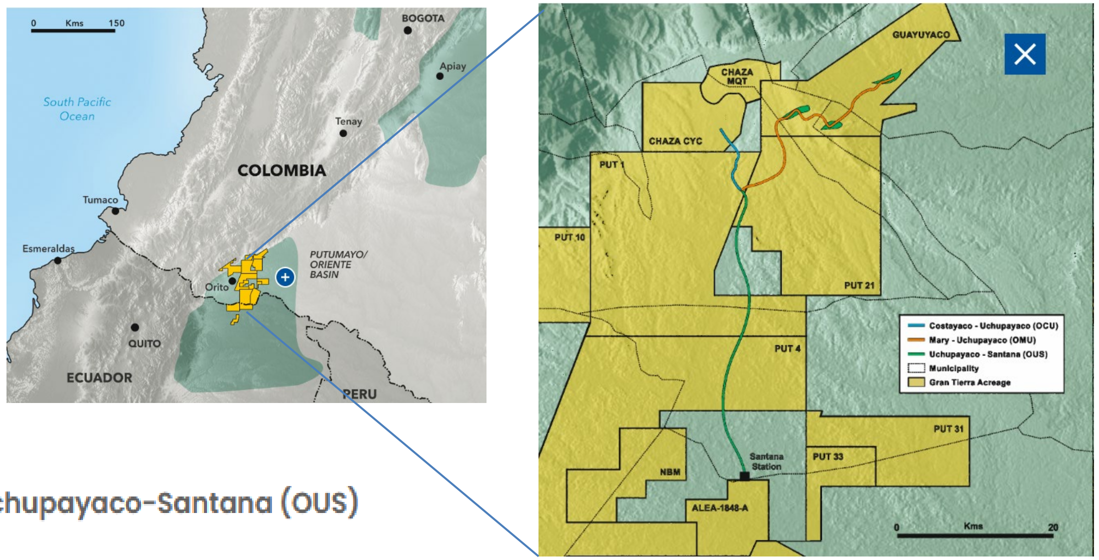
Flow rate: 803 27.531 BPD – Crude Oil @ 12 cST, SG:0.88; 86ºF

Discharge pressure: 900 psi

Option 1: Centrifugal Pump BB3, 598 BHP @ Efficiency: 70.5%

Oprtiion 2: 3 screw pump, 489.15 BHP @ Efficiency: 86.2%

Power Savings: 58.665 kW/month (622K US$ for two years) Pumps payoff in the first two years of operations.



Uchupayaco-Santana (OUS)

Diameter (Inch): 8 5/8

Length: 41.96km

Initial point: Uchupayaco Trap

Final point: Santana Station

Transportation Capacity: 27,600 BPOD

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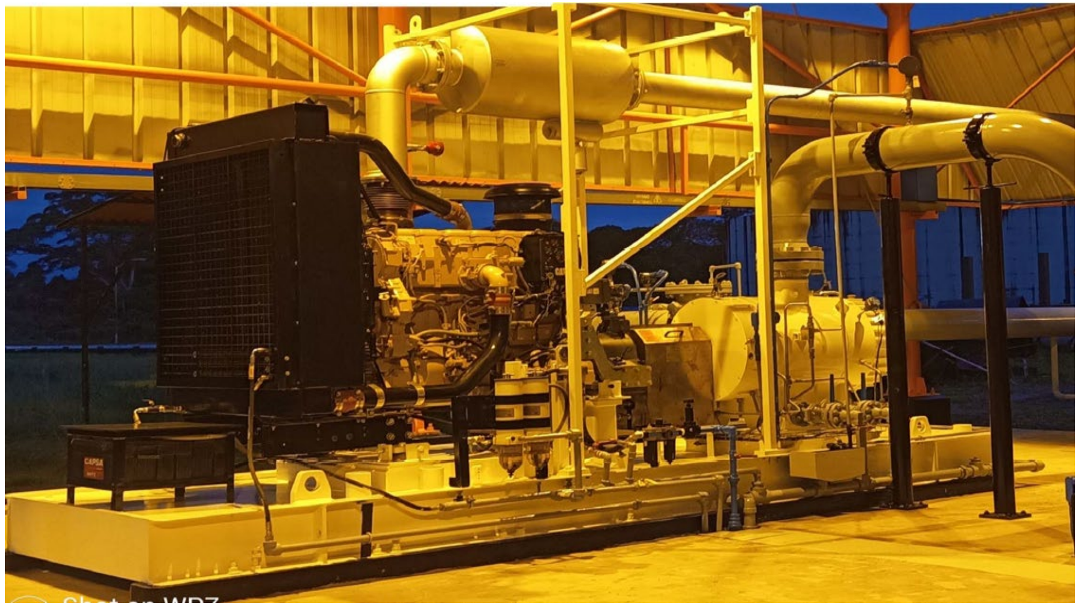
Case Study

Case Study 2: Main Pipeline Booster – Replacement of one pump BB1 to one Twin Screw Pump (Peru)

Centrifugal Pump BB1	4 Screw (Twin Screw Pump)
Flow: 15,000 BBPD	Flow: 23,500 BBPD
Driver: Diesel Turbine	Driver: Diesel Engine
Viscosity: 700 cST	Viscosity: 700 cST
Discharge pressure: 46 Barg	Discharge pressure: 46 Barg
Power: 800 BHP	Power: 470 BHP
Fuel-Diesel: 250 Gal/Hr	Fuel-Diesel: 25 Gal/Hr
Saving per month at 4 US$ per Gal = 648,000 US$ (Payoff of one pump unit in 1 month)	



2024

Case Study

Case Study 3: Main pipeline booster - Twin Screw Pump (Canada)

Pipeline: 64km, 24”.

Product: Hot Dilbit @ 145C

Flow: 711 m3/h

Diff. Press.: 3920 kPa

Viscosity: 30 cST

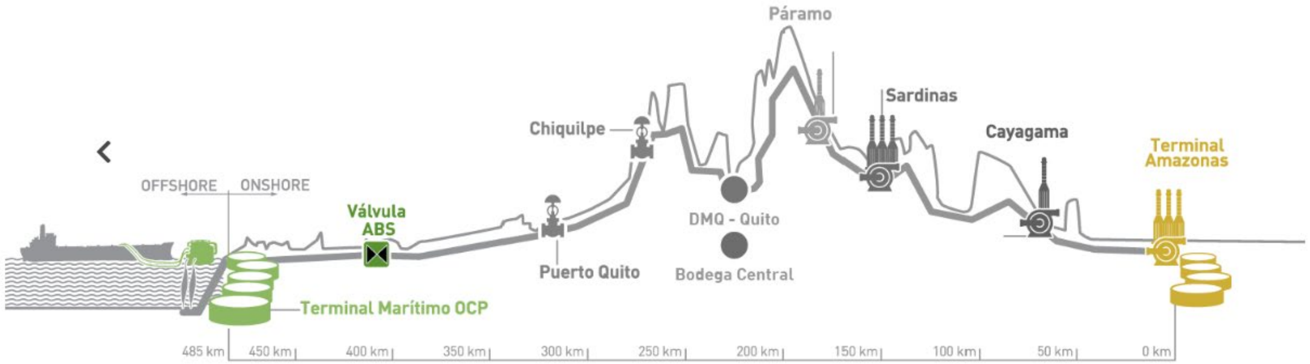
Power: 1500 hp

Twin screw pumps was selected over centrifugal pumps since pipeline cold start was a possibility; this pumps is used as pipeline start-up pump and main booster. Also, diluent injection was a concern with Centrifugal Pumps as flashing at the pump suction can be present and potential risk with gas locking and sever cavitation was considered.

2024

Case Study

Case Study 4: Suction Booster and Start Up Pipelines - 4 Screw (Twin Screw) Pumps (Ecuador)



Product: Sales crude oil

Flow: 800 m3/h

Diff. Press.: 200 psi max.

Viscosity: 70 - 1000 cST

Power: 800 hp

Twin screw pump are used for cold Start-up of the main pipeline and push the cold viscous product up hill (Andes Mountains). After, the main pipeline booster Centrifugal Pumps are aligned and activated with lower viscosity crude oil. The twin screw pumps are switched to Suction Booster mode to the main centrifugal, due to the much lower NPSHr.

CPS 2024

Case Study

Case Study 3: Lateral/Feeder Pipelines - 3 Screw Pumps (Canada)

Product:	Sales crude oil
Flow:	230 gpm
Diff. Press.:	1440 psi max.
Viscosity:	180 cST
Speed:	1150 rpm
Power:	250 hp

Time in operation: Since early 2000's

End-user developed and implemented with the OEM a system to monitor remotely the condition of the Idler screws balance cups; making possible to plan maintenance, increase safety and reliability of the unit. Reducing substantially OPEX. OEM implemented the change as standard in its product line worldwide.

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Thank you for your time