Well site facilities Onshore Conference
Sept. 2018

Ken Goh, Senior Project Engineer
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Adjustable choke design to handle erosion

masterflo.com

The leader in choke technology

An evolving industry

Ever more demanding production processes

100 years + of production process evolution

Far from Titusville in 1859 the last 25 years of production evolution brought us…

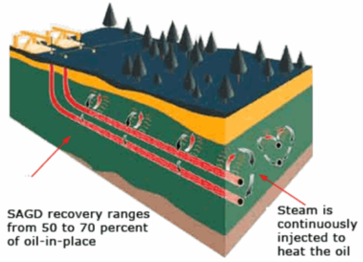
- Shale oil & gas production
- SAGD Process
- Cyclic steam process
  - More aggressive “Well management programs”
  - Increasing sand volume being used
  - Resisting temptation to reduce flow back time
  - More demanding well stimulation techniques

Today’s producer have to handle more aggressive process conditions.

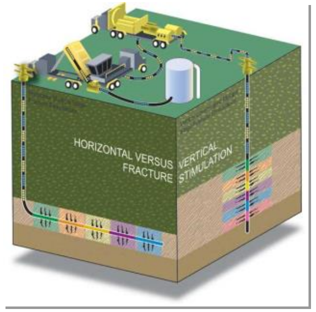
–Sand and organic erosion (up to 15%)
–High temperature (700F+)
–Higher pressure (15K and 20K)
  • Creating Initial higher pressure delta with often supersonic speed conditions
–High flow rates over a wide range of pressure conditions true well life.
  • Maintaining flow rate with a delta reducing by over 3000psi over well depletion cycle.
–Hydrate formation, that’s always fun…

–And yes.. Sand.. Did we say sand?

SAGD / Cyclic Steam



Unconventiona O&Gl



15% sand and organics from SAGD production

Evolving demands

Demanding production processes

Sand is proving to be the new enemy …

- Coated, man made or natural, It's all the same.. **Evil.**
- A common denominator for all unconventional O&G production, sand erosion is costly in multiple ways;
  - Down time
  - Lost of production
  - Difficult implementation of the well management program
  - High parts and maintenance cost
    - **High cost of ownership**

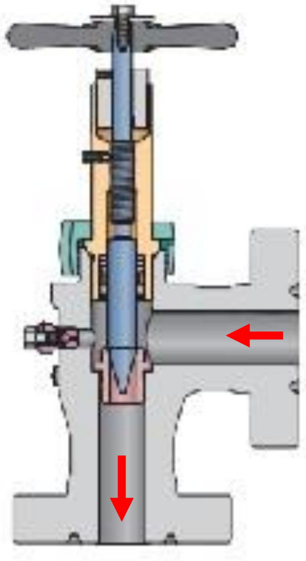
While operation wants more from the choke..

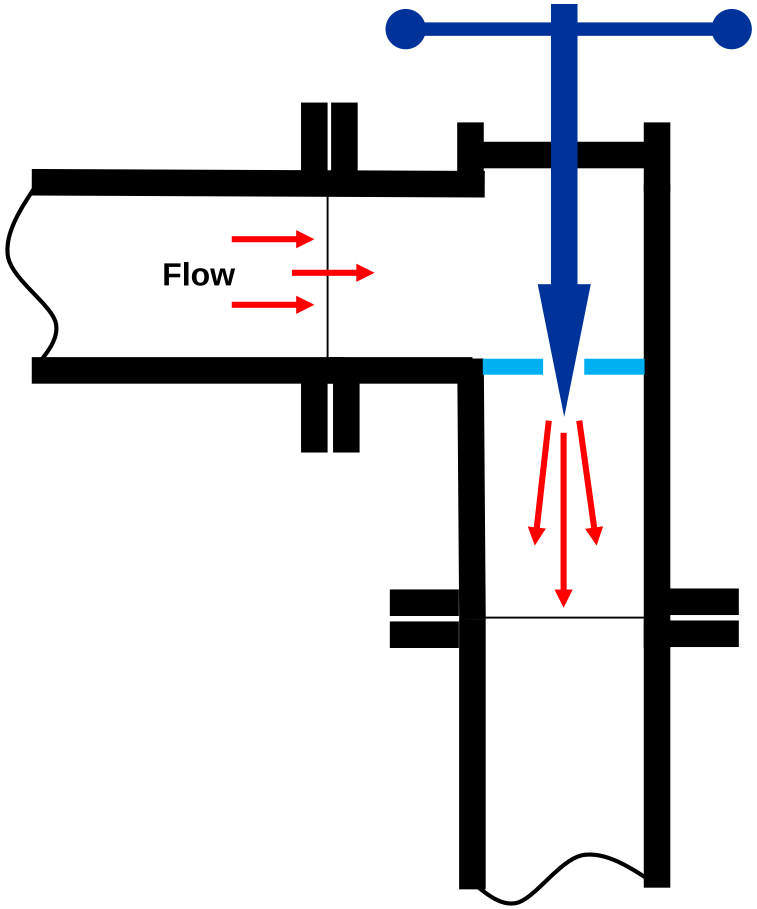
- Controllability
- Repeatability
- Reliability
- Long life trim
- Long term shut off capabilities
- Increase up-time
- Low cost of ownership

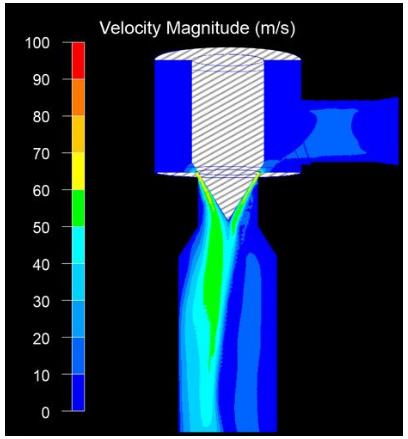
Fact: Your production choke valves are your primary control elements, and a major determinant in your ability to achieve profitability.

- **Every production choke designs has merits,**
- **But they also have limitations when faced with sand…lets review…**

Needle and Seat Choke (Circa 1925)



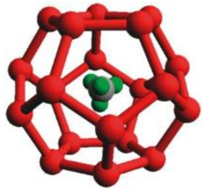


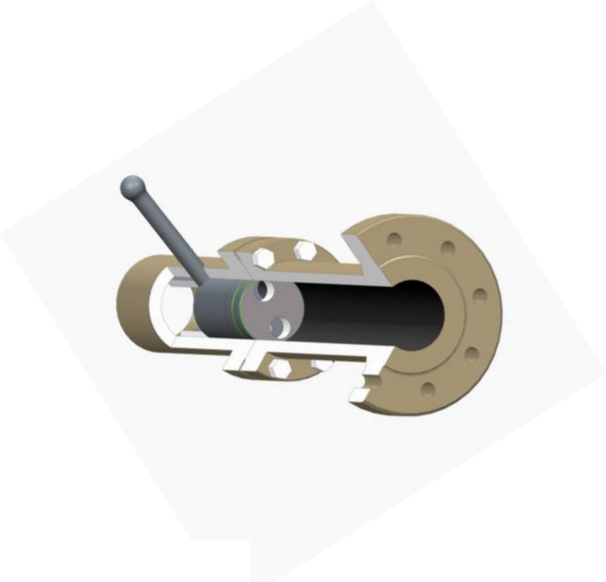


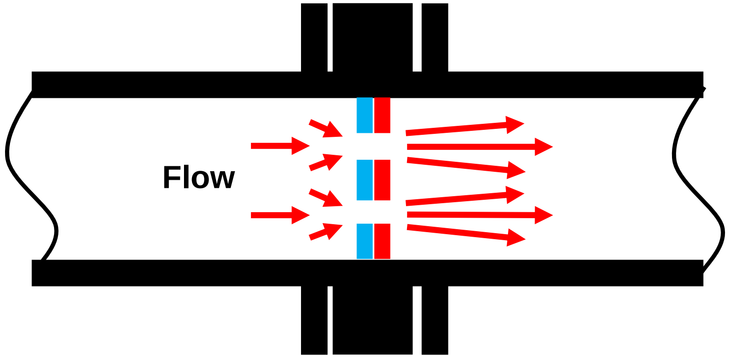
Results of sand erosion

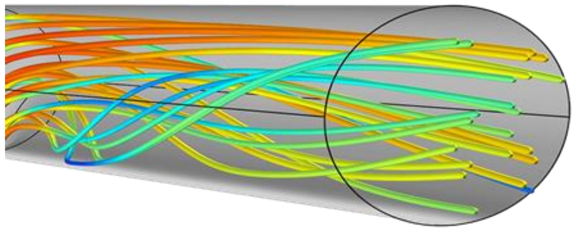
M.O.V Wafer Choke (Circa 1950)

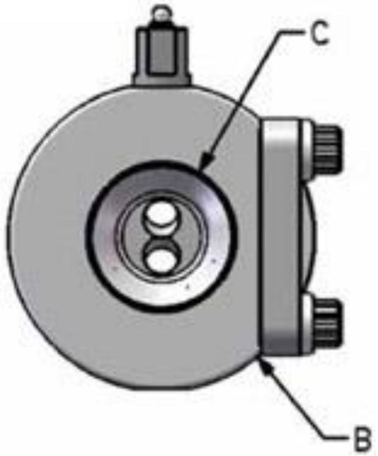
Hydrate









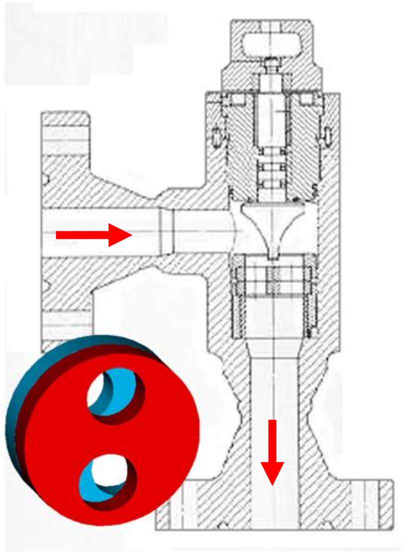


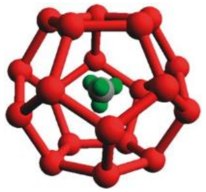
Results of sand erosion

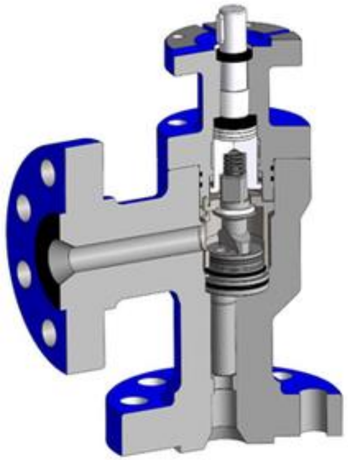
Results of sand erosion

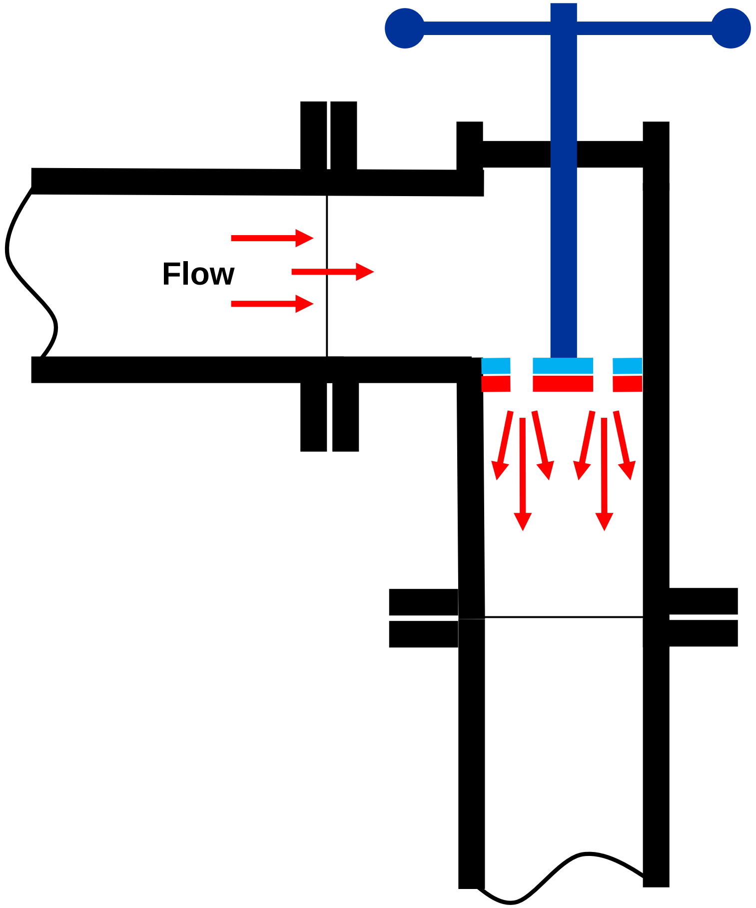
Results of sand erosion

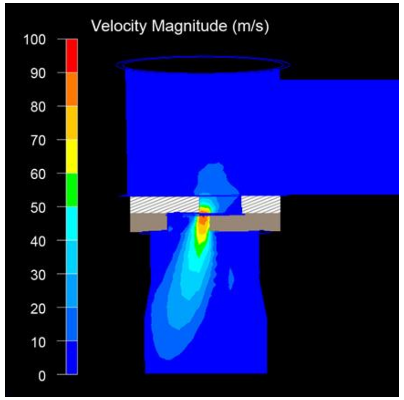
M.O.V Choke (Circa 1950)











Results of sand erosion

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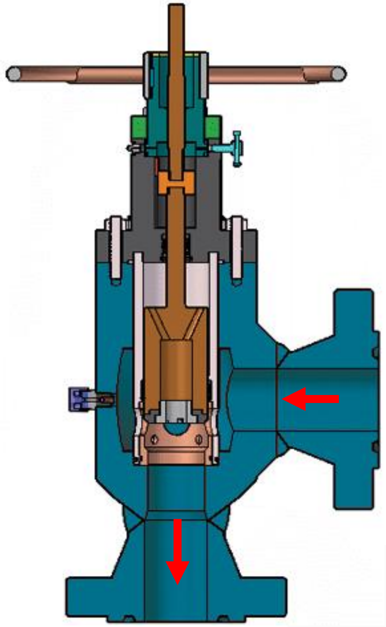
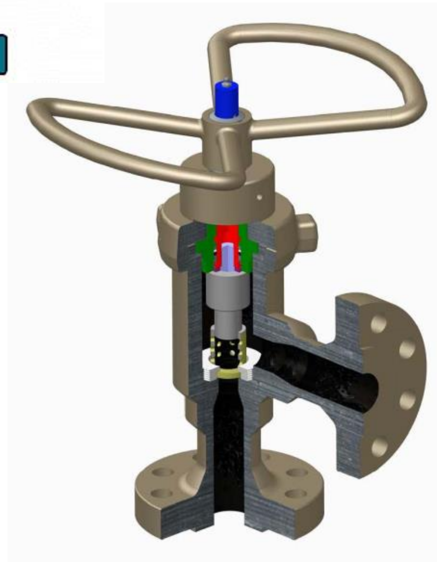
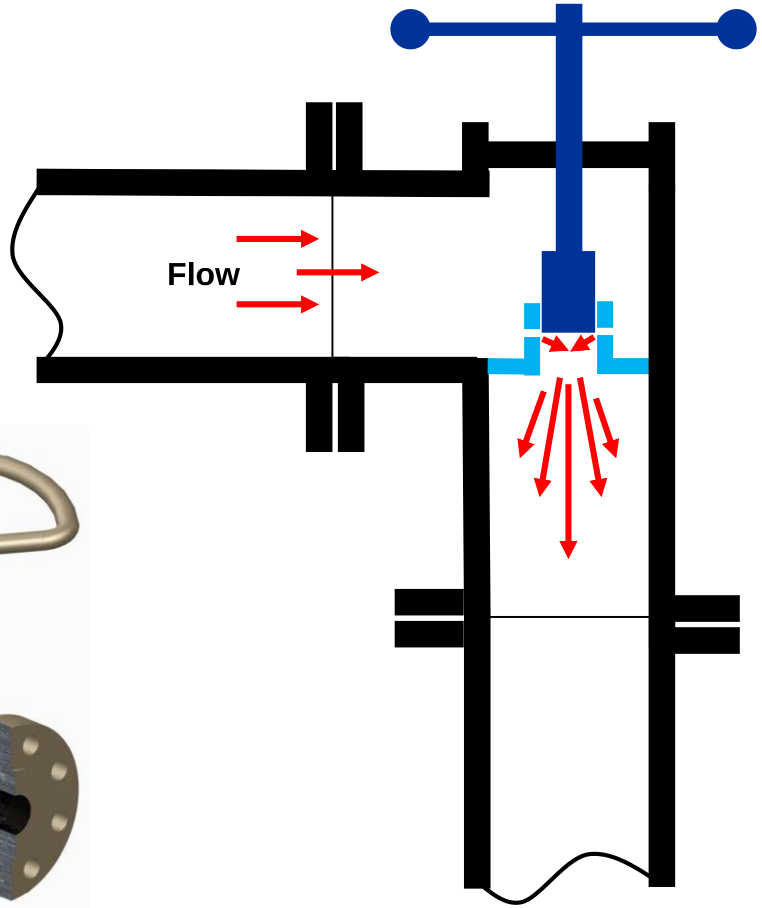
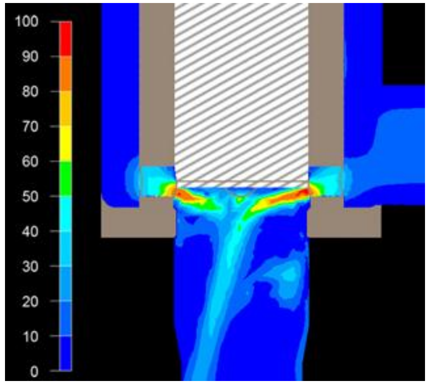
Plug and Cage Choke (Circa 1975)



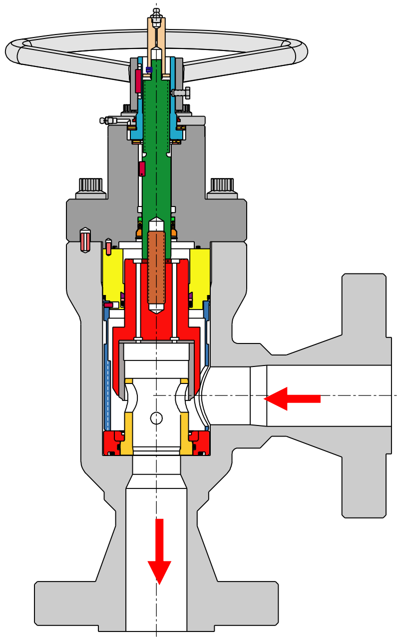


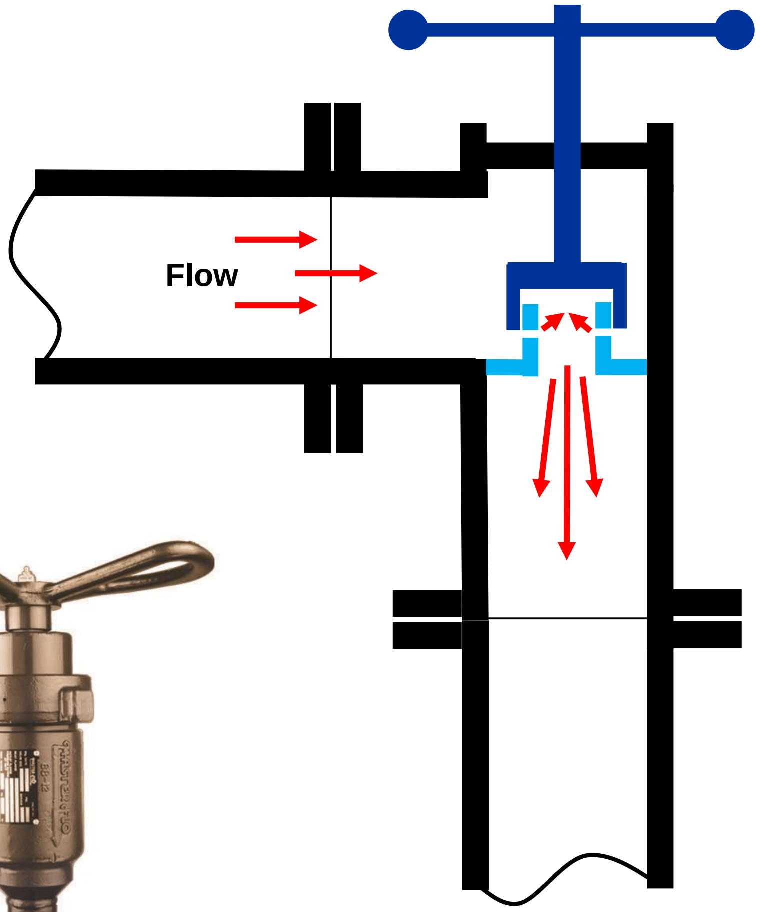


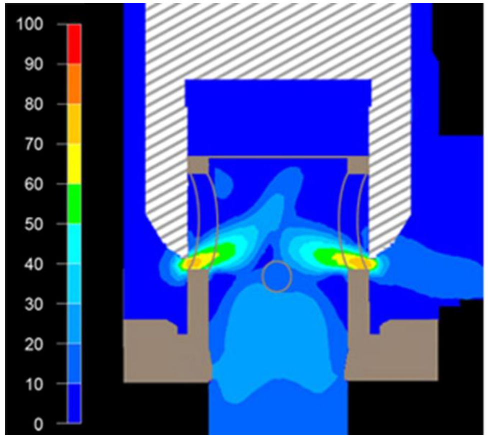


Results of sand erosion

External sleeve design (evolving since 2000)







Results of sand erosion

Advance technology

Evolved trim designs

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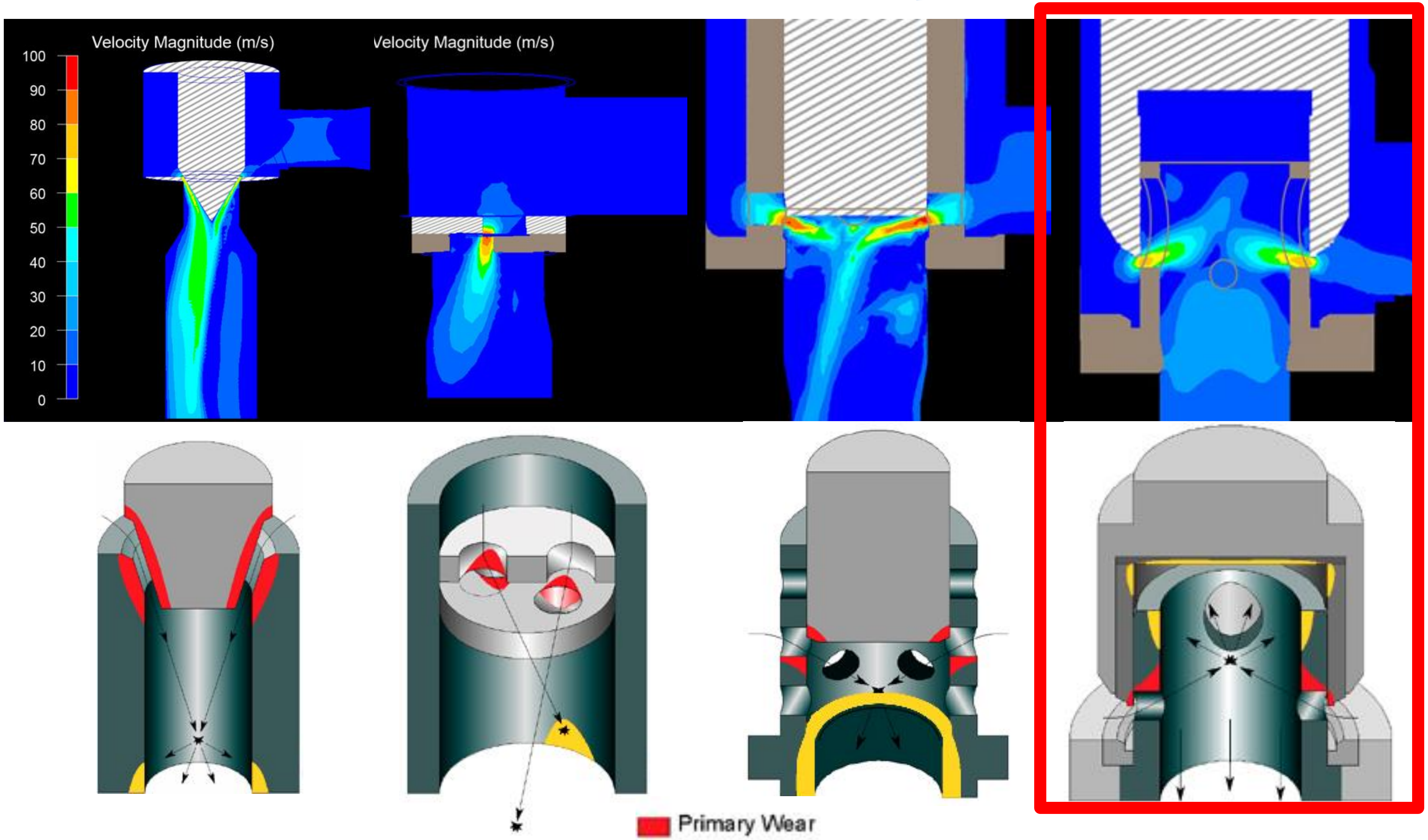
Erosion Performance Comparison: Adjustable Chokes



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Design Criteria: Driving Factors

The science behind the design

- **Pressure** – *API 6A Energy Distortion & ASME Methods, Material Mechanical Properties.*
- **Temperature** – *API 6A Temp Class, Annex G Derating, Material Mechanical Properties, etc*
- **Corrosion** – Sweet and Sour, NACE MR0175
- **Erosion** – Velocity, Energy, Material
- **Flowrates** – Adjustability, Flow Coefficient (Cv), Choked flow, etc
- **Controllability** – Cv curve, Adjustment Resolution, etc
- **Cavitation** – *Fl* factor
- **Hydrate Formation** – *Xt* factor
- **Automation** – Safety, Monitor, Labor, $$$
- **Cost** – Cost of Ownership

Continuity Equation: (V-A)

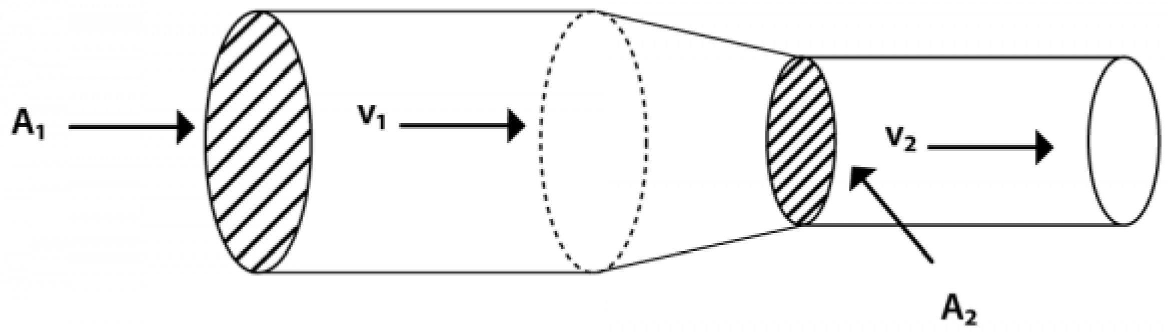
- Conservation of Mass:

$$\dot{m}_1 = \dot{m}_2$$

$$\rho_1 V_1 A_1 = \rho_2 V_2 A_2$$

$$V_1 A_1 = V_2 A_2$$ Incompressible Fluid

$$\frac{V_1}{V_2} = \frac{A_2}{A_1}$$ $A_1 > A_2$; $V_1 < V_2$



Bernoulli's Principle: Venturi Effect (P-V)

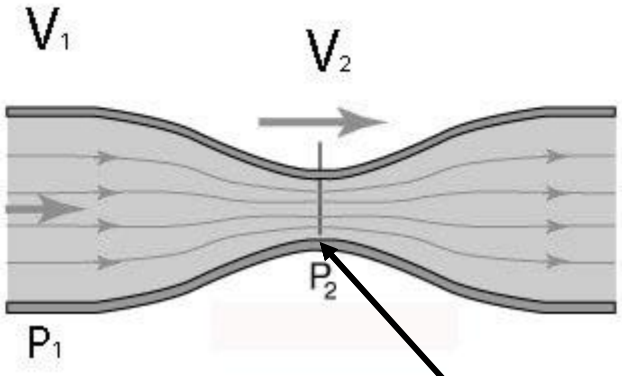
- Conservation of Energy: Kinetic ⇄ Potential

$V\uparrow \longrightarrow P\downarrow \qquad V\downarrow \longrightarrow P\uparrow$

$P_1 > P_2 \qquad V_1 < V_2$

$\Delta P = P_{in} - P_{out}$

P_{in}



P_{out}

Vena Contracta

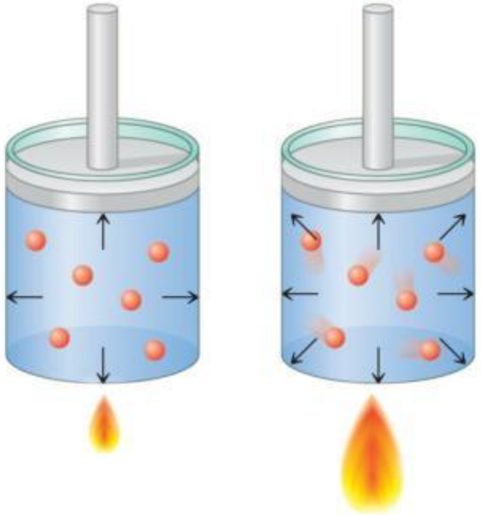
Gay-Lussac's Law: Joule-Thomson Effects (P-T)

The science behind the design

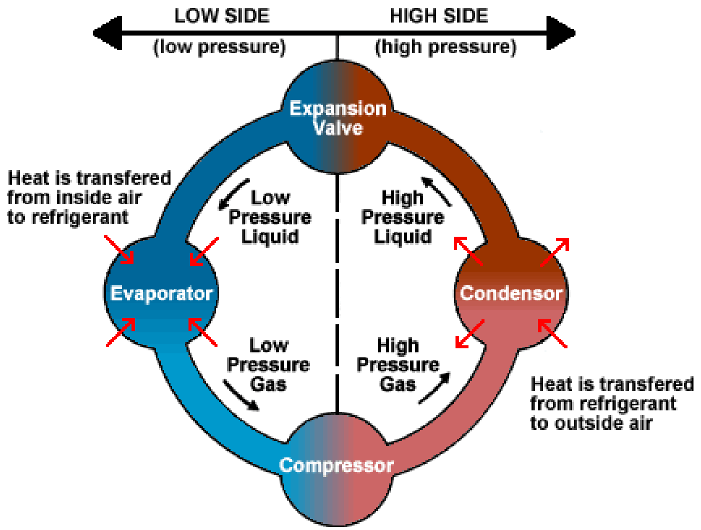
- **Conservation of Energy: Internal ⇄ Potential**

- the <u>pressure</u> exerted by a gas is <u>directly related</u> to the Kelvin <u>temperature</u>.
- V and n are constant.

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$



$$T_1 < T_2 \; ; \; P_1 < P_2$$



- **The act of reducing the pressure of gas flow through a restrictor results in a phenomenon known as the Joule-Thomson Effect.**
- **Cooling occurs because work must be done to overcome the long-range attraction between the gas molecules as the move farther apart during the expansion process.**

Erosion Control

Trim Life Prediction Model

- Erosion = Function (Fluid Kinetic Energy, Subject Material)
  - Fluid Kinetic Energy: $E_k = ½ mV^2$
  - Subject Material: Primary & Secondary Wear Areas

Erosion Control

Erosion Management

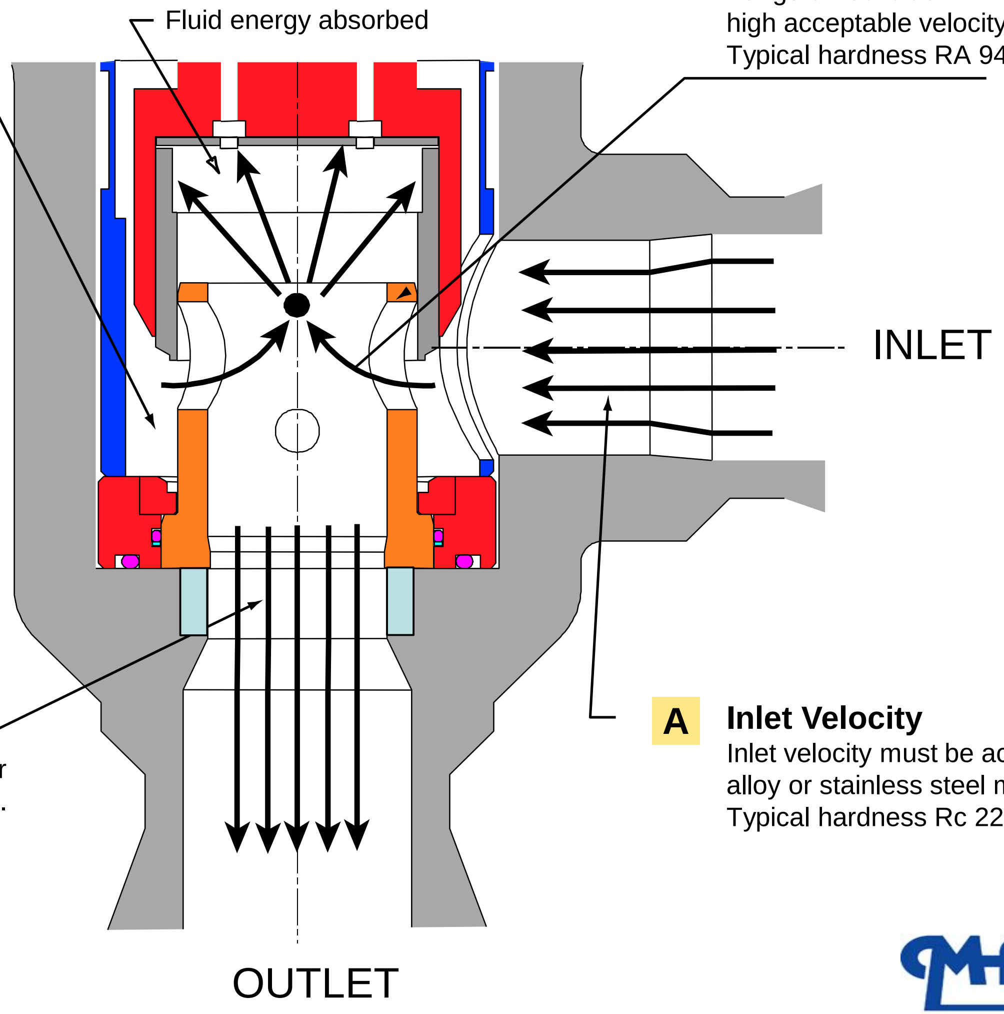
- **Energy Management**
  - Impingement – Energy dissipation
- **Velocity Management**
  - Valve Internal Design – Slower is better
- **Material Management**
  - Hardness + Corrosion resistance

Velocity Control

The science behind the design

B **Body Velocity**
Velocity must be acceptable for alloy or stainless steel material.
Typical hardness Rc 22

C **Orifice Velocity**
Tungsten Carbide Trim allows high acceptable velocity.
Typical hardness RA 94



D **Trim Exit Velocity**
Velocity must be acceptable for alloy or stainless steel material.
Typical hardness Rc 22

A **Inlet Velocity**
Inlet velocity must be acceptable for alloy or stainless steel material.
Typical hardness Rc 22

Erosion management

The science behind the design

Upstream

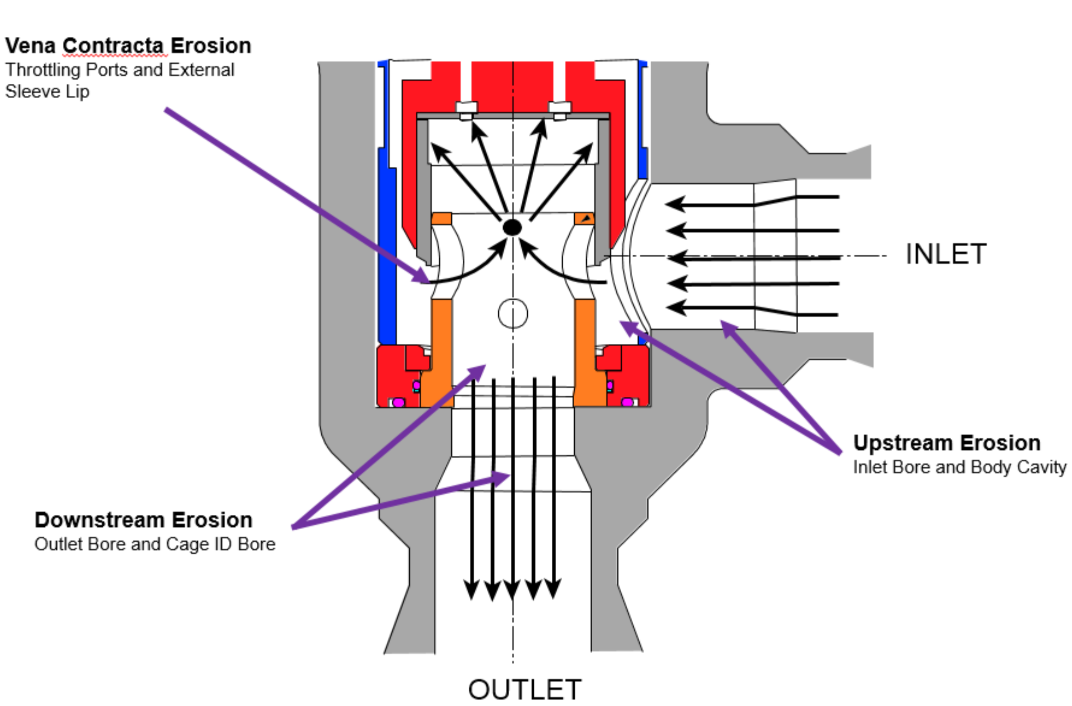
- Longer Deadband
- Larger Choke Size
- Larger Body Inlet Bore or End Connection

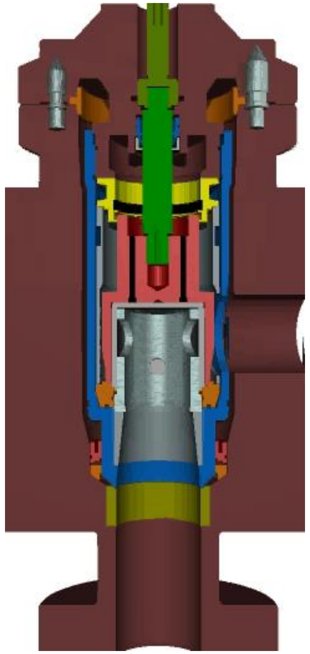
Vena Contracta

- Proper sized ports (Minimum Perimeter)
- 2 or 4 ports
- Harder Materials (>Ra 94 5CB TC)

Downstream

- Larger Choke Size - Larger Cage ID
- Larger Body Outlet Bore or End Connection
- Body Outlet TC Wear Sleeve
- HES Choke





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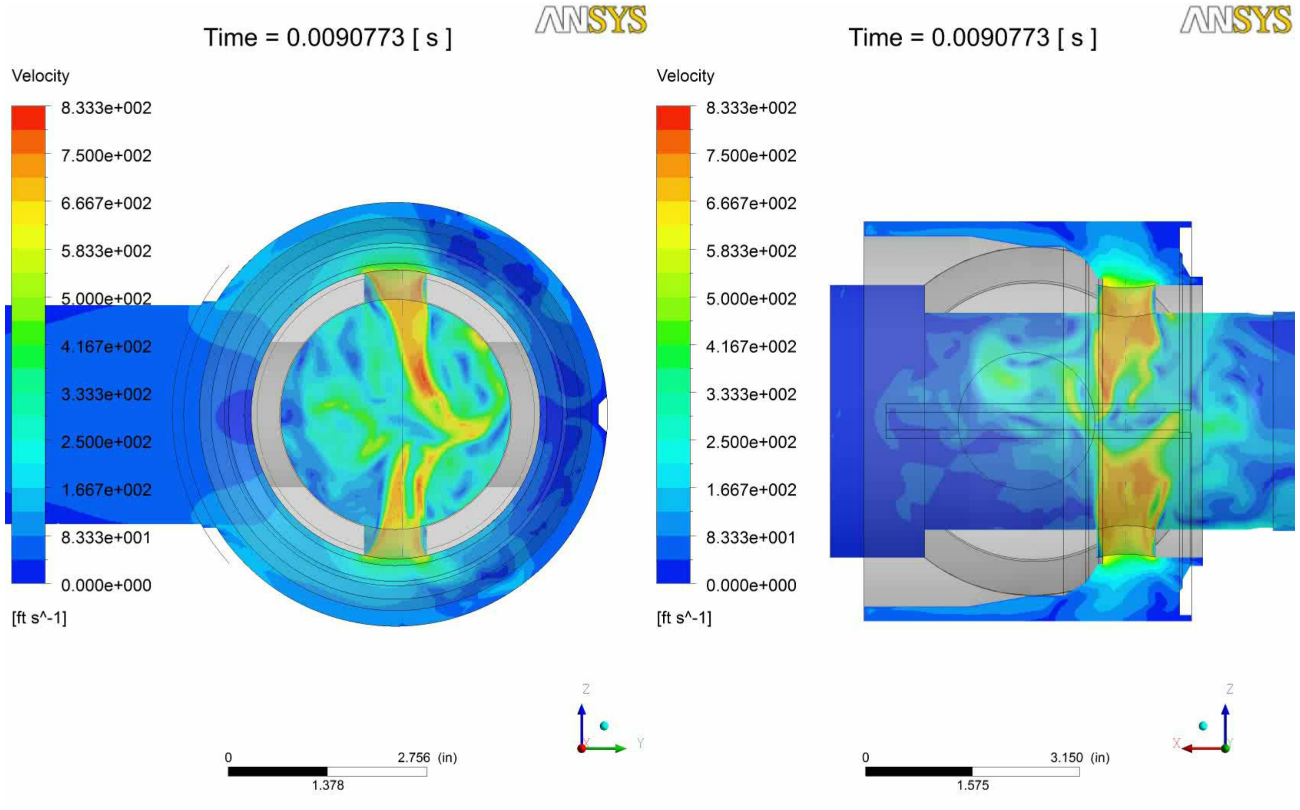
Velocity Control

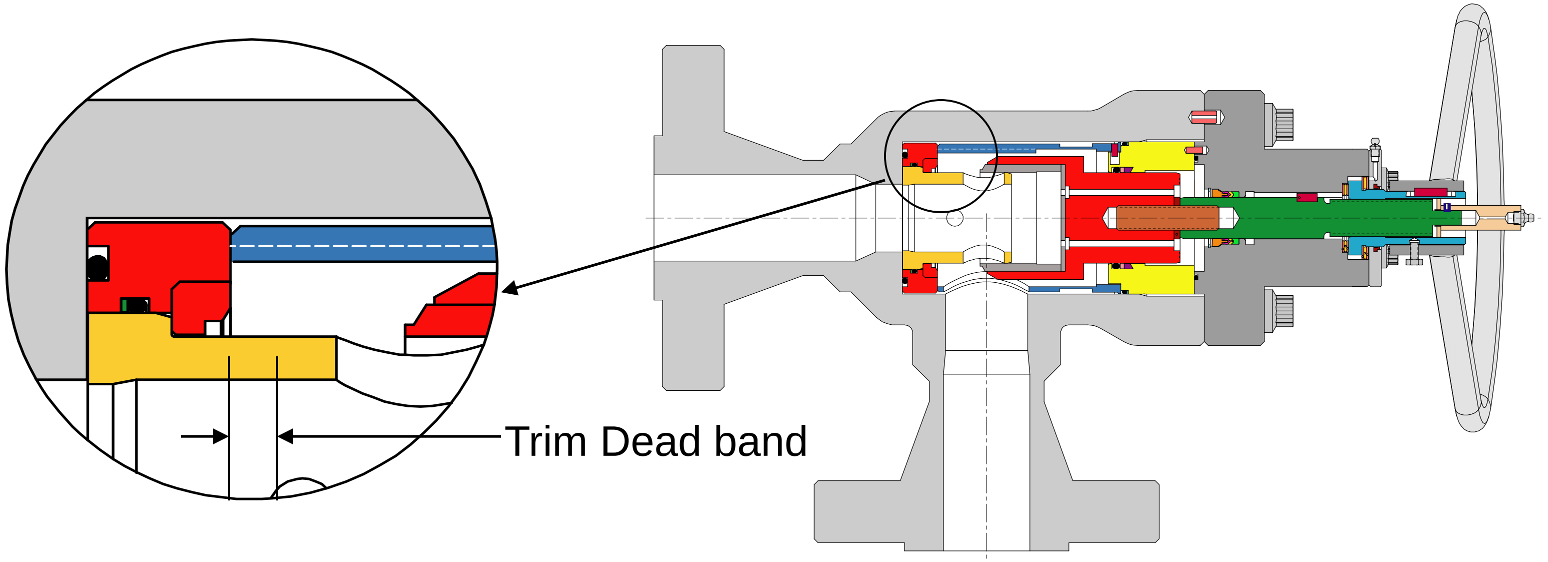
External Sleeve and cage Aerodynamics/Hydrodynamics

Empirical data demonstrates that fluid impingement will effectively dissipate 25% or more of the energy.



Trim Design

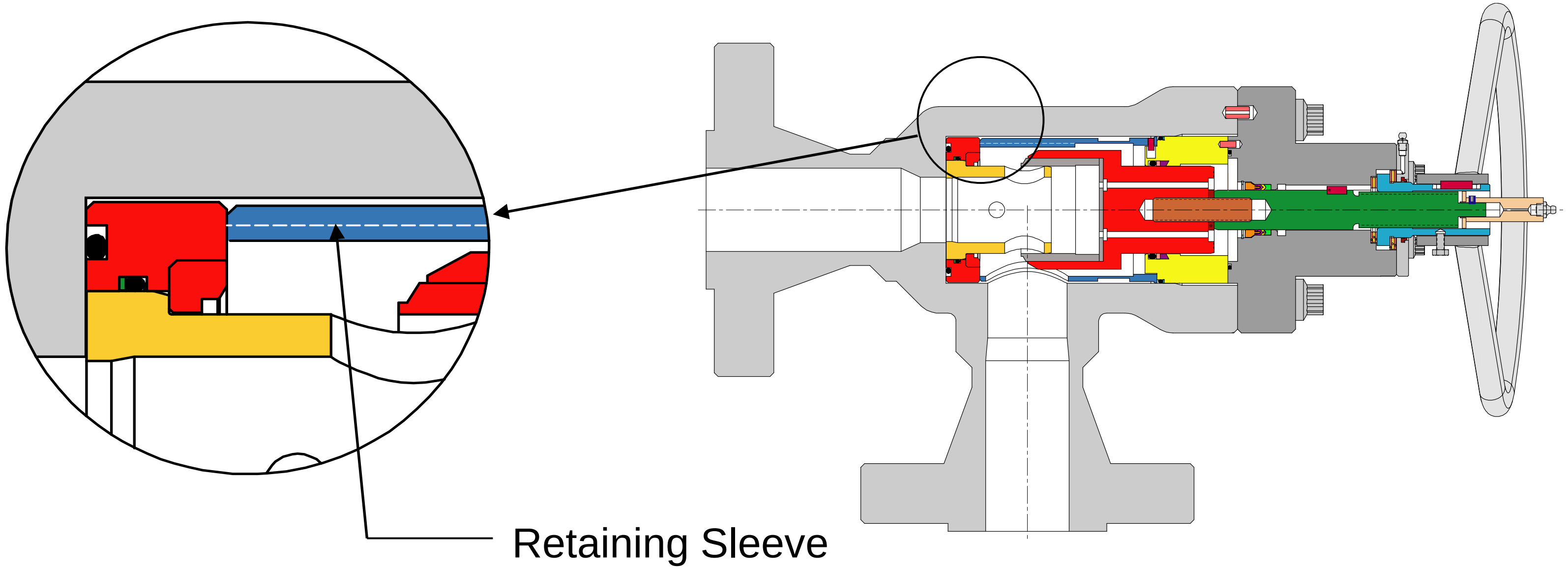
Design evolution



Trim Dead Band

- Protects seat surface from high velocity fluid associated with trim ports
- Increases body annulus area for reduced velocity

Design evolution

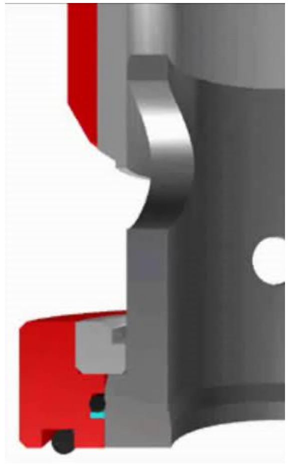


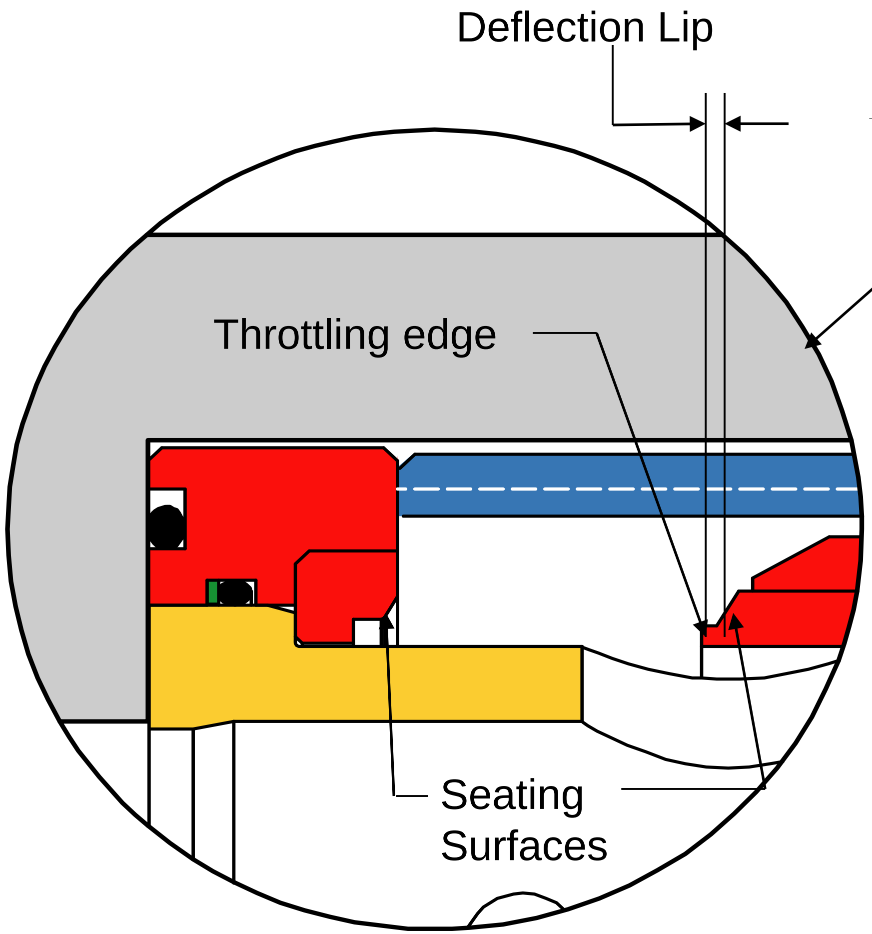
Retaining Sleeve

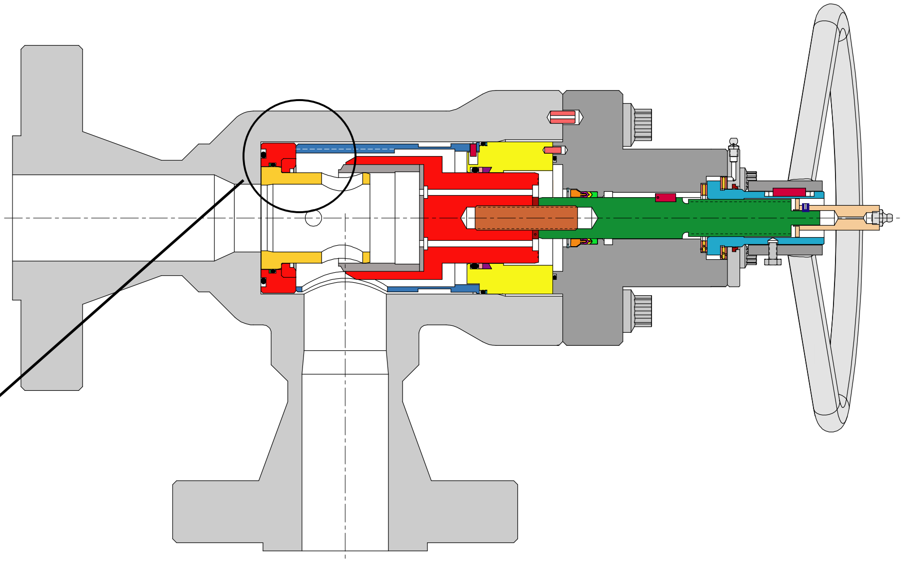
- ❑ Protects body from fluid velocity and potential erosion
- ❑ Eliminates the need for wetted body threads
- ❑ Facilitates ease of service with no special tooling.
- ❑ Allows self-aligning trim components

Trim Design

Design evolution







Shut-off protection

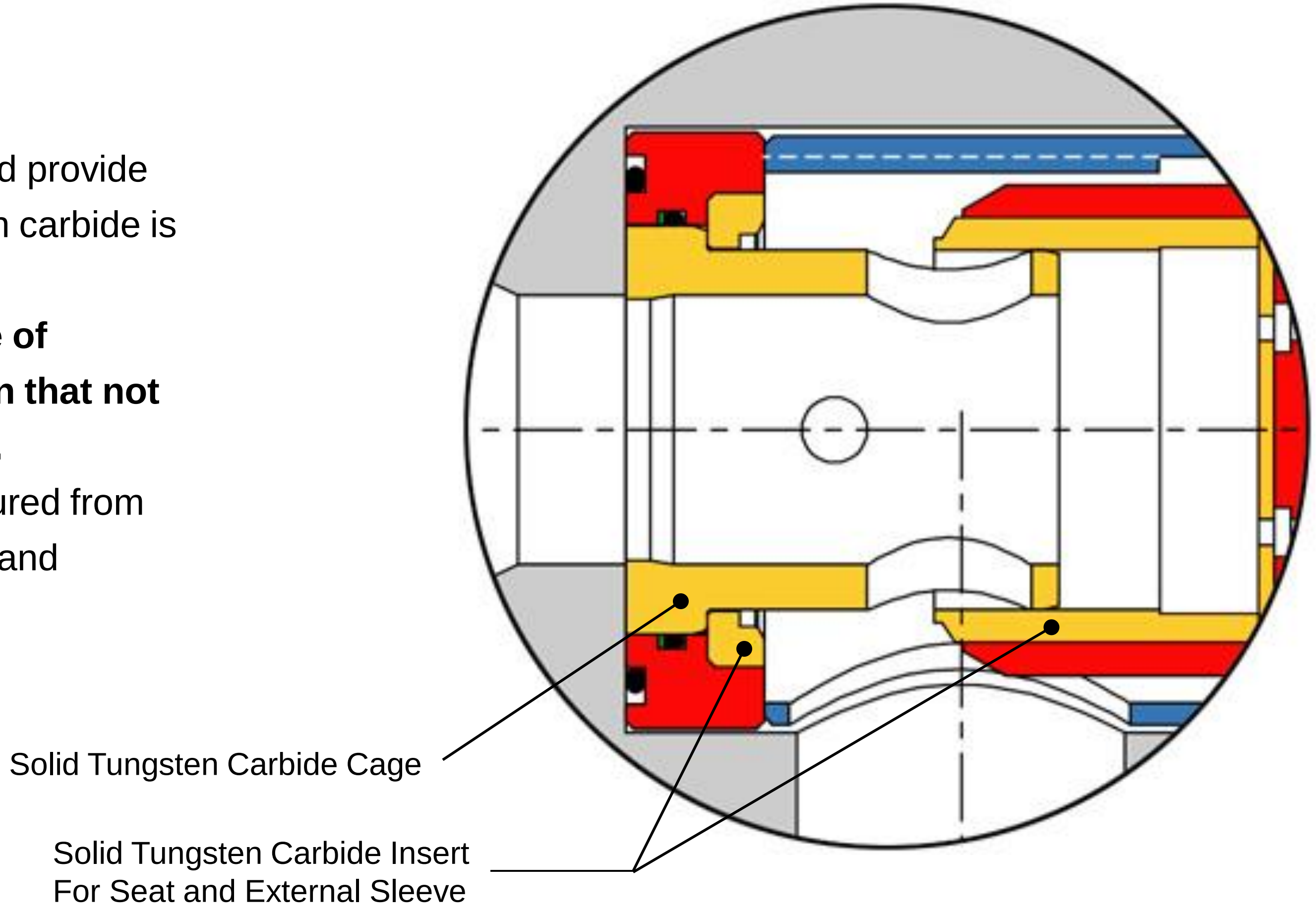
- Deflection lip on collar separates throttling surface from seating surface for prolonged shut-off
- Metal to Metal seat surfaces provide extended Class 5 shut-off

Material & Design Advancements

Material evolution

Tungsten Carbide

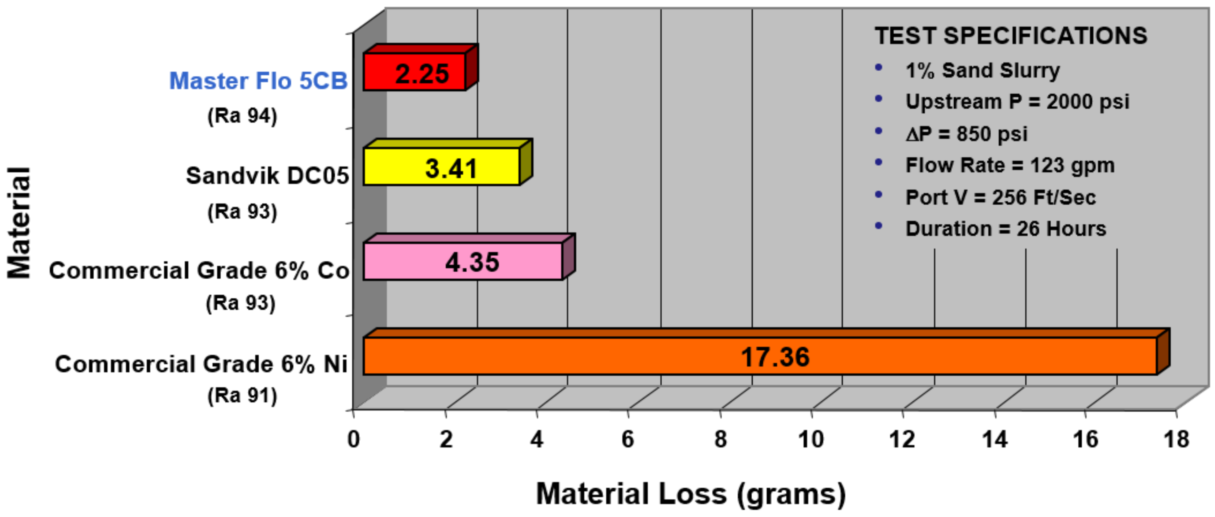
- To be able to contain the energy and provide suitable erosion resistance tungsten carbide is used for the trim components
    - **Hardness being the feature of interest, it should be known that not all carbide grade are equal.**
- Carbide grade should be manufactured from binder consisting of Cobalt, Nickel, and Chromium.



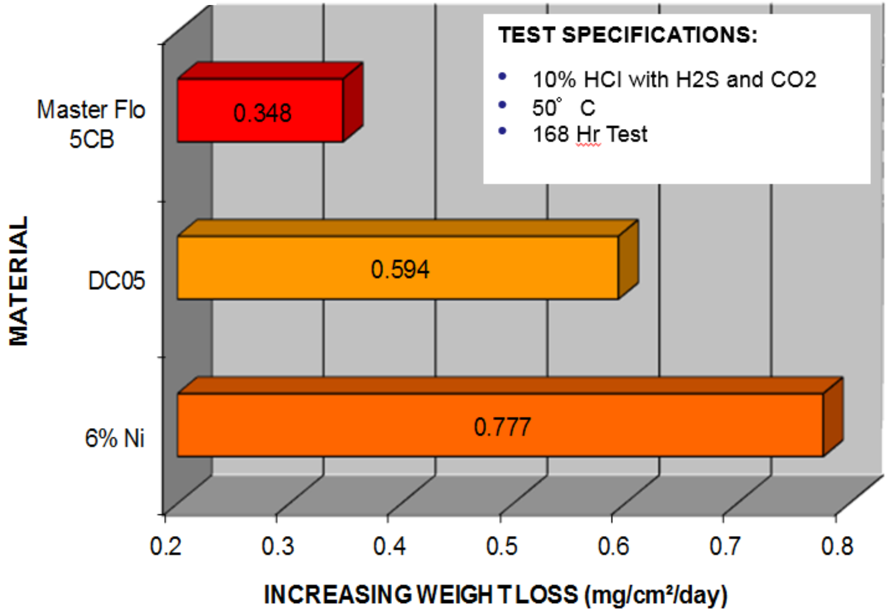
Trim Material – Erosion

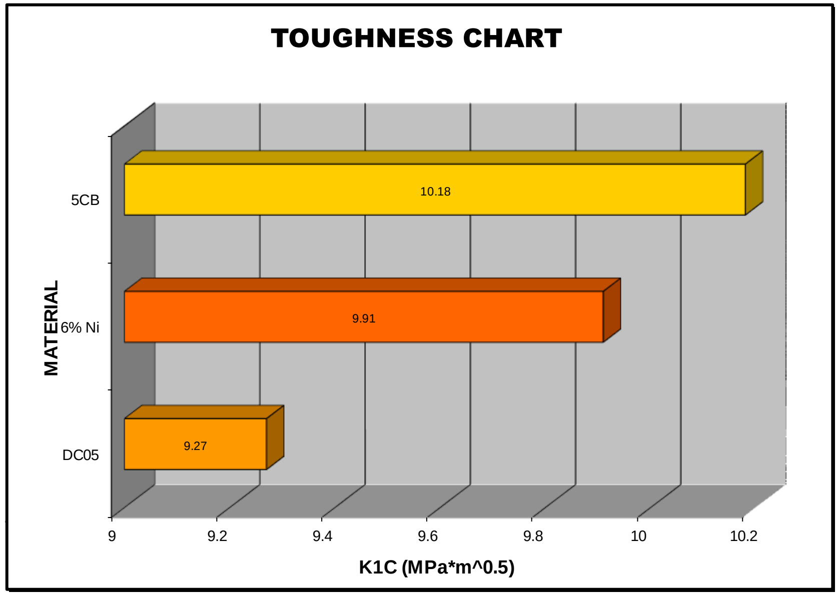
Material evolution

Erosion Test Results



Corrosion Testing





Erosion Calculation: Trim Life Prediction

TRIM LIFE PREDICTION

DATA INPUT TYS-GP1

	DESCRIPTION	UNITS	VALUE
	CHOKE SIZE	P1,P2, etc.	P2
	ACTUAL BEAN SIZE	64 th's	42
	SAND FLOW RATE	kg/hr	19.00
	TRIM LIFE EXPECTANCY	%	100
1)	NOZZLE OUTLET VELOCITY	m/s	60.33
	TRIM TYPE		TC5CB
2)	UPSTREAM TEMPERATURE	ºF	120
	UPSTREAM PRESSURE	psi	6000
3)	SPECIFIC GRAVITY OF STD. OIL	-	0.73
	FLOW RATE OF STD. OIL	Bbl/d	2000
	SPECIFIC GRAVITY OF WATER	-	1
	FLOW RATE OF WATER	Bbl/d	7000
	FLOW RATE OF STD. GAS	MMSCFD	10

DATA OUTPUT

NOZZLE PORT VELOCITY=	197.71	m/s
ACOUSTIC VELOCITY OF FLUID=	442.81	m/s
TOTAL MASS OF SAND PRODUCED=	18536.34	kg
TRIM LIFE=	975.6	hours
	40.6	days
	0.11	years

Where sand depletion over time will increase life cycle exponentially..

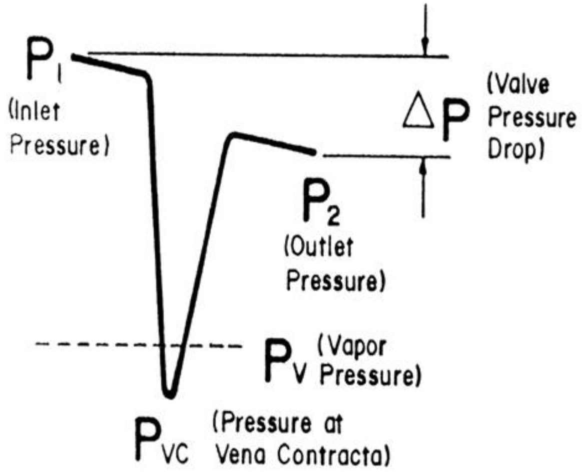
Max. (Worst) Case Scenario

- Max. Pressure/Pressure Drop
- Max. Temp
- Max. Oil Flow Rate
- Max. Gas Flow Rate
- Max. Velocity
- Min. Trim Life

F_L or X_t (Pressure Recovery) Factor

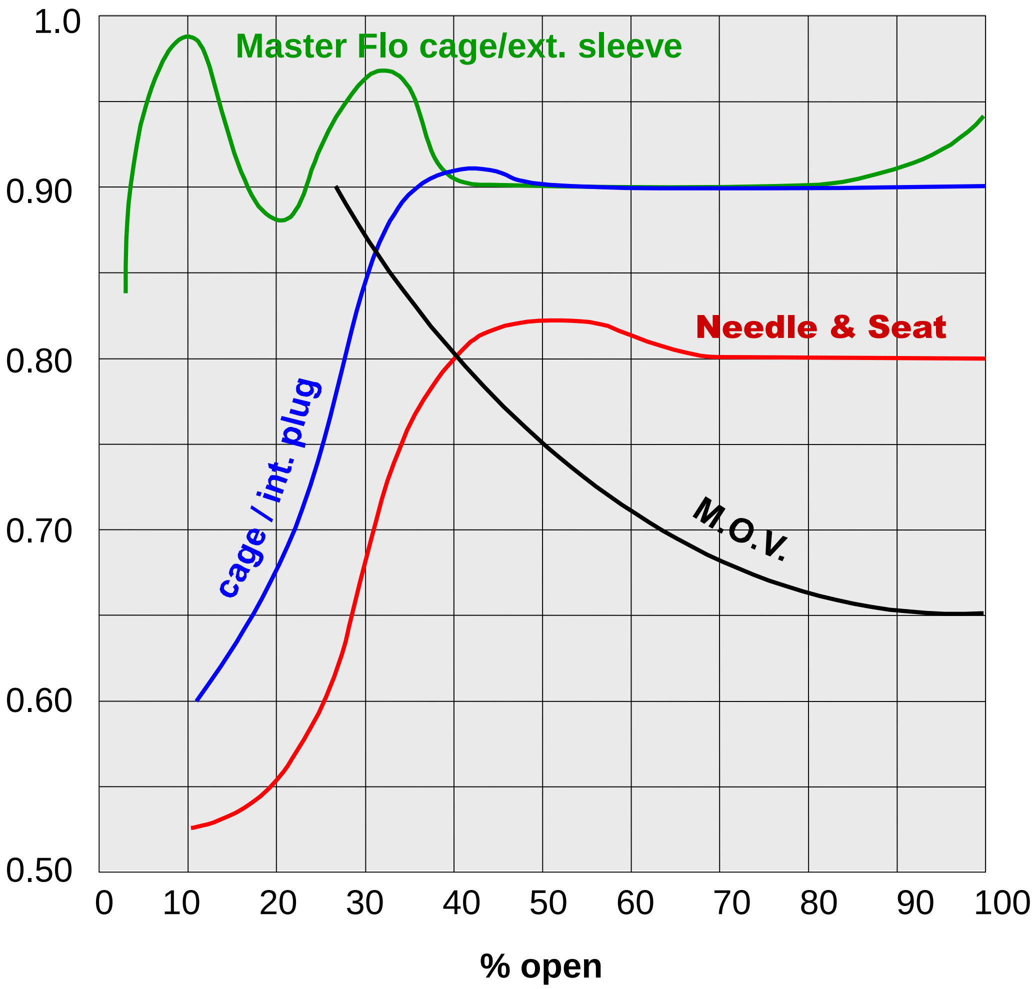
Material evolution

- **Provides a correlation between pressure drop and lowest pressure point in the valve (P_{VC})**
- **Lower P_{VC} means lower temperature**



$$F_L^2 = \frac{P_1 - P_2}{P_1 - P_{VC}}$$

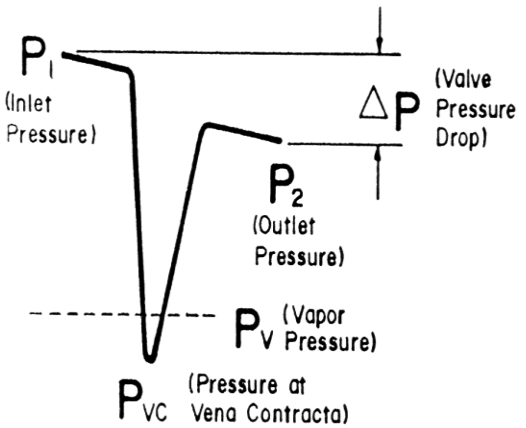
i.e. the higher F_L number, the lower the risk of cavitation

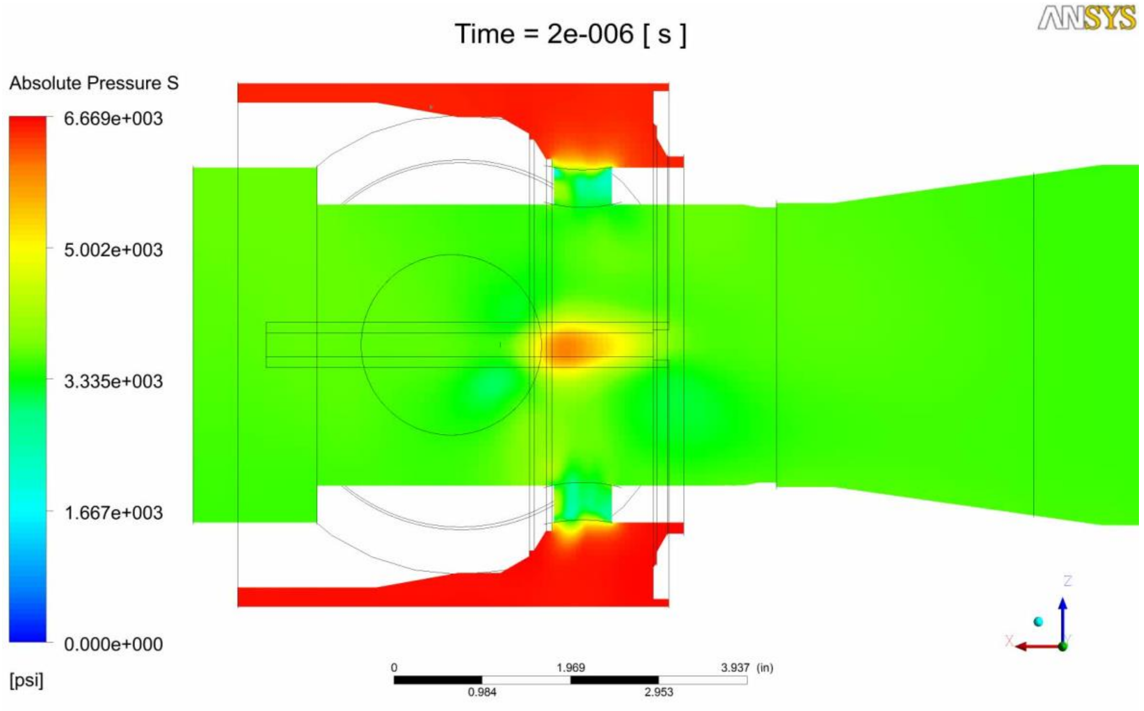


Hydrate formation

External Sleeve and cage Aerodynamics/Hydrodynamics

In order to best mitigate hydrate formation and cavitation, the “vena contracta” and recovery factor information is crucial and more predictable.





Choke Trim Designs For Different Applications

Standard 4-port

- General Purpose
- Excellent For Erosion Control
- Good Controllability
- Available In SS, Stellite Or Tungsten Carbide

2-stage

- Available In Standard And High Pressure Drop
- Good For Cavitation Control
- Good For Noise Control
- Available In Stellite Or Tungsten Carbide

Laminate 4-port

- Used In High Impact Applications To Reduce Catastrophic Failure (Tested To Withstand 300 J Energy)
- Absorbs Impact Energy In Outer Cage; Soft Core Between Cages Acts As A Crack Arrester
- Continuous Bond Technology Maintains Structural Integrity
- Available In Tungsten Carbide

Custom Multi-port

- Reduction In Noise
- Improved Controllability On Startup
- Available In SS Or Tungsten Carbide

Labflo

- Excellent For Noise Control
- Excellent For Cavitation
- Liquid, Gas And Multi-phase Applications
- 3 Distinct Pressure Drop Configurations along Travel
- Available In Tungsten Carbide

Well Cleanup

- Used In High Impact Applications To Eliminate Catastrophic Failure
- Absorbs Impact Energy In The Stainless Steel Outer Cage
- Recommended For Flowback And Well Cleanup Operations
- Proprietary 5CB Tungsten Carbide On All Erosion Sensitive Areas

MASTER FLO®

Conclusion

Trim design comparison

	POS	MOV	N&S	P&C	C&S
Adjustable	No	Yes	Yes	Yes	Yes
Shut Off Capability	No	Yes	Yes	Yes	Yes
Jet Impingement Energy Dissipation	No	No	No	Yes	Yes
Throttling = Sealing surface	Yes	No	Yes	Yes	No
Hi-speed Jet into Body Outlet	Yes	Yes	Yes	Yes	No
F*l* and/or X*t* Factor	Lo	Lo	Lo	Med	Hi
Torque/Thrust Requirements	N/A	Hi	Lo	Lo	Lo
Rotating Stem (Stem Seal)	N/A	Yes	Yes	No	No
Custom Trim	No	Kinda	No	Yes	Yes
Control Resolution	No	Bad	Bad	Good	Good

Conclusion

- **Process conditions are getting more demanding.**
  - **More sand downhole during frac**
  - **Higher flow rates**
  - **Increase emphasis on controllability and repeatability to meet well program demands.**
  - **Cost containment against sand erosion effects taking a front seat.**

- **Advance trim design and materials advantages…**
  - **With it's ability to control velocity at the trim, the external sleeve design provides;**
    - **Long trim life**
    - **Lowest cost of ownership**
    - **Increase Up-time**
    - **Improved controllability and repeatability**
    - **Long term shut off capability**
    - **Proving itself to be best defense against the effects of sand erosion.**

End.