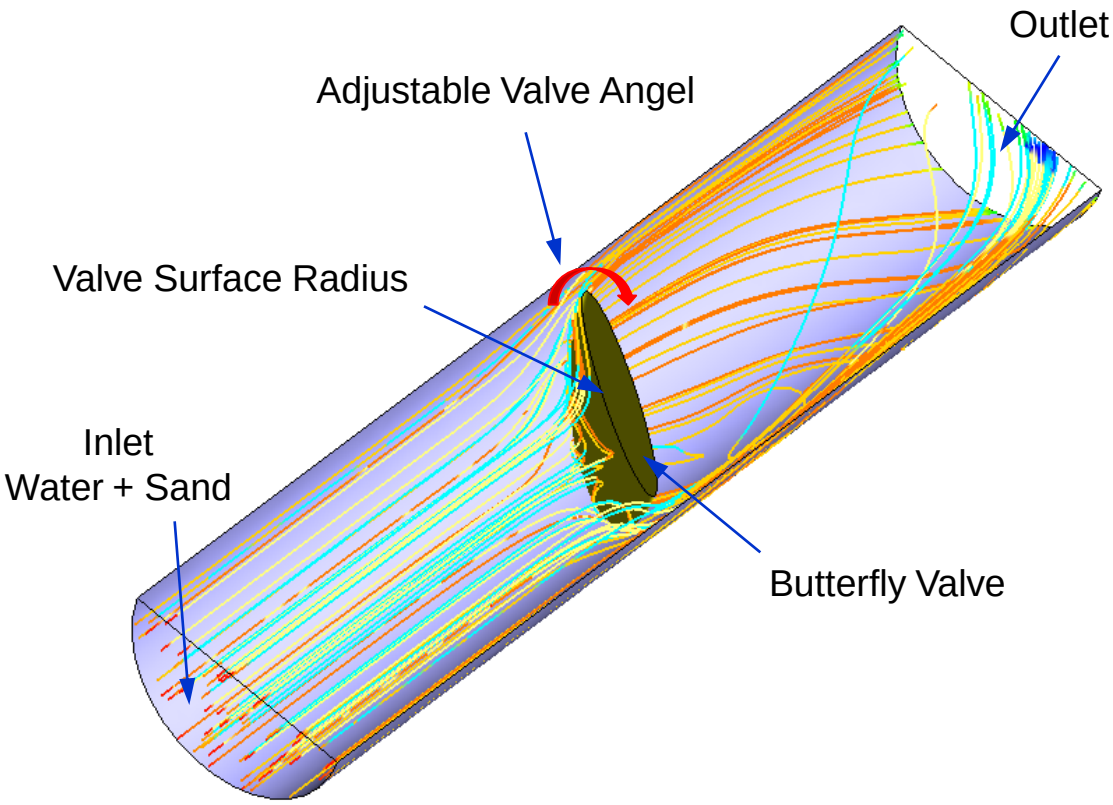
Robust Design of a Butterfly Valve

OptiY GmbH - Germany

Butterfly Valve



Design Specifications

Design Parameter Space:

- Valve Angle = [30, 60] deg
- Valve Radius = [1, 7] mm

- Angel Tolerance = 2 deg
- Radius Tolerance = 0.1 mm

Initial Nominal Parameters

Design Parameters

Name	Nominal	Tolerance	Unit
Valve Angle	45	30	deg
Valve Radius	4	6	mm
Inflow rate	5	0.25	m s^-1
Sand Grain Roughness	2e-005	1e-006	m
Water Density	997	50	kg m^-3
Water Molar Mass	18.02	0.9	kg kmol^-1

Process or Environment Parameters:

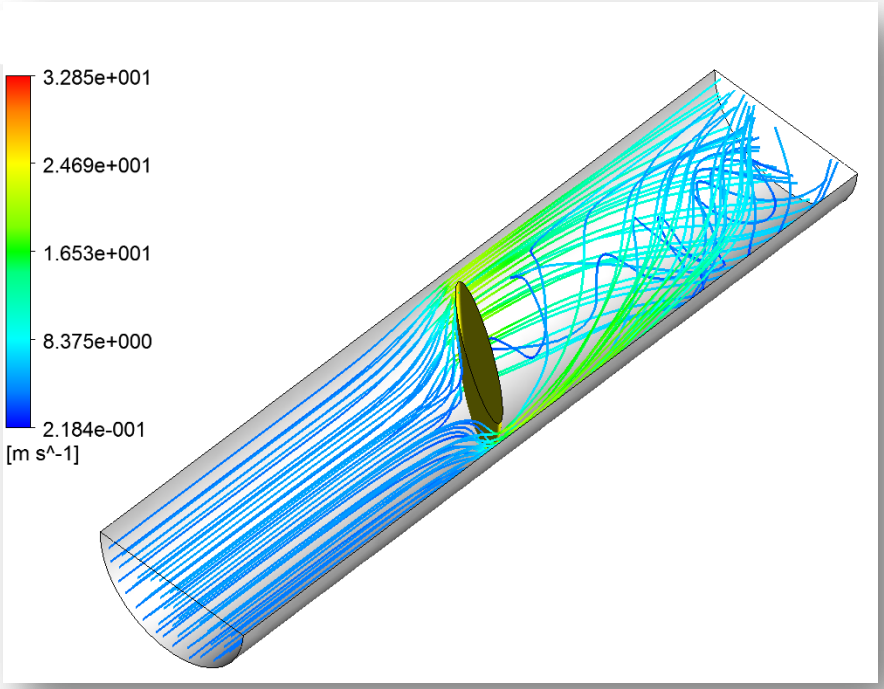
- Inflow Rate = 5 ± 0.125 m s^-1
- Sand Grain Roughness = 20 ± 0.5 µm
- Water Density = 997 ± 25 kg m^-3
- Water Molar Mass = 18.02 ± 0.45 kg kmol ^-1

Functional Requirements:

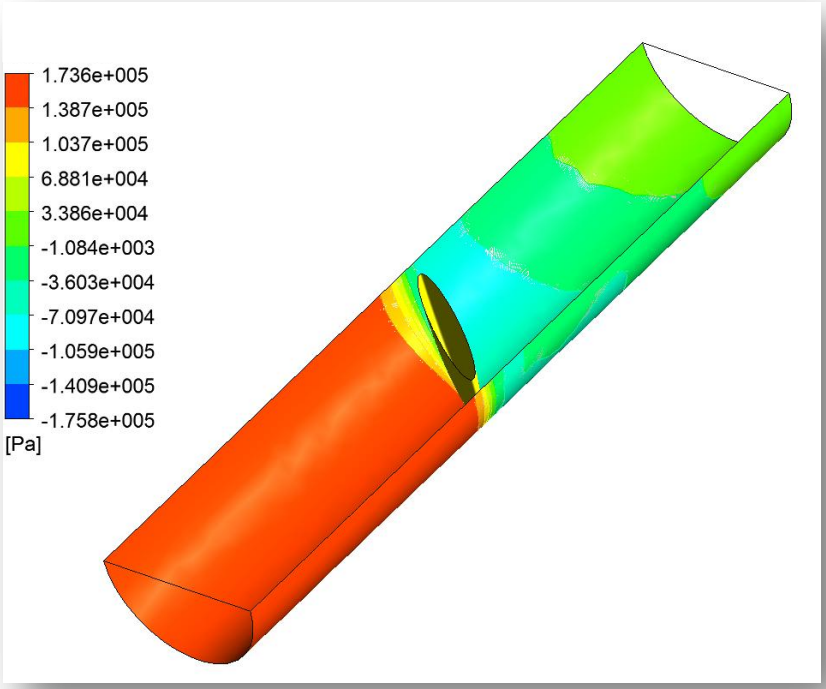
- Outlet Mass Flow Rate = [-0.06, -0.054] m s^-1
- Outlet pressure = minimal as possible
- Valve Erosion = minimal as possible
- Wall Erosion = minimal as possible

Nominal CFD-Simulation

Flow Velocity

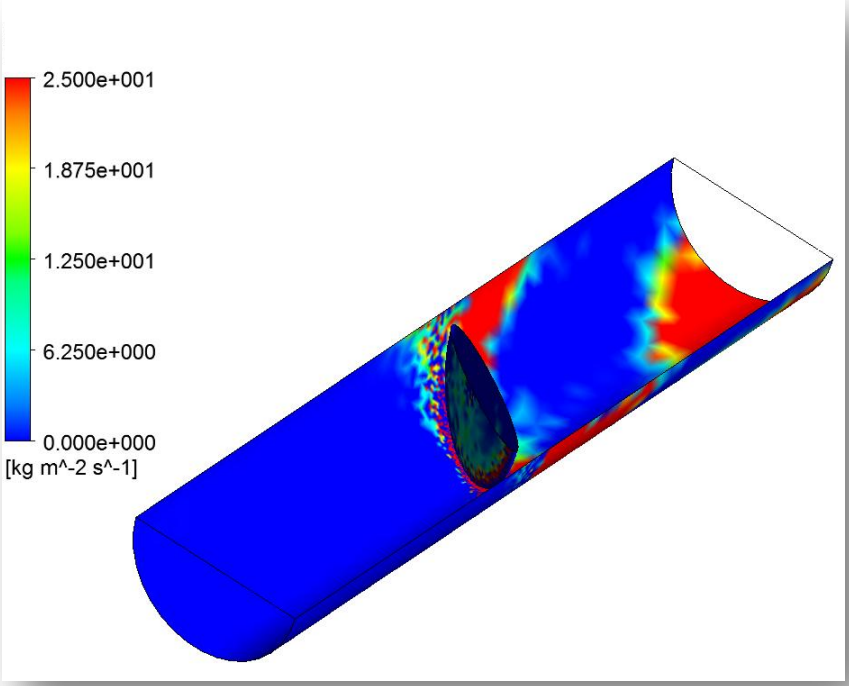


Wall Total Pressure

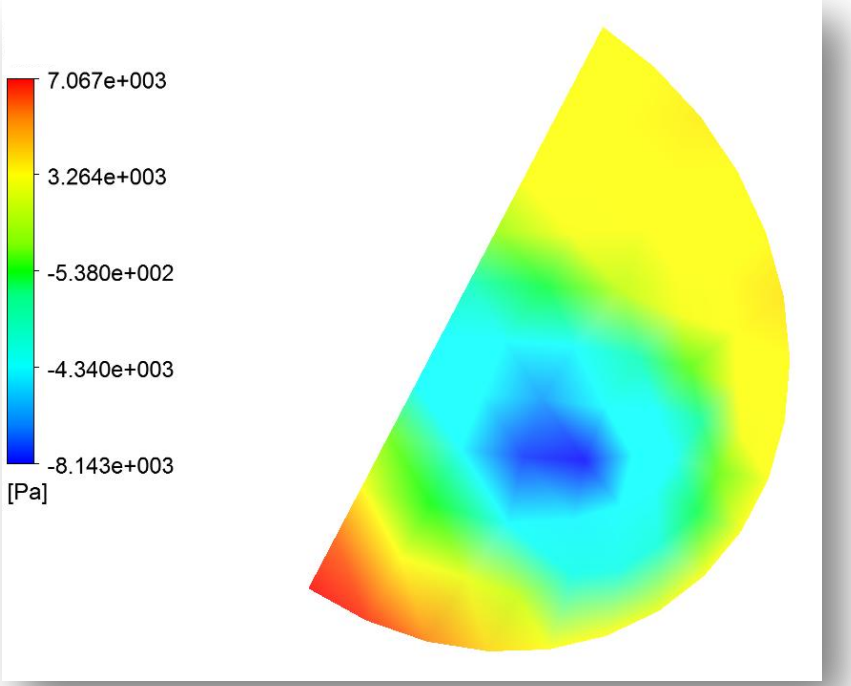


Nominal CFD-Simulation

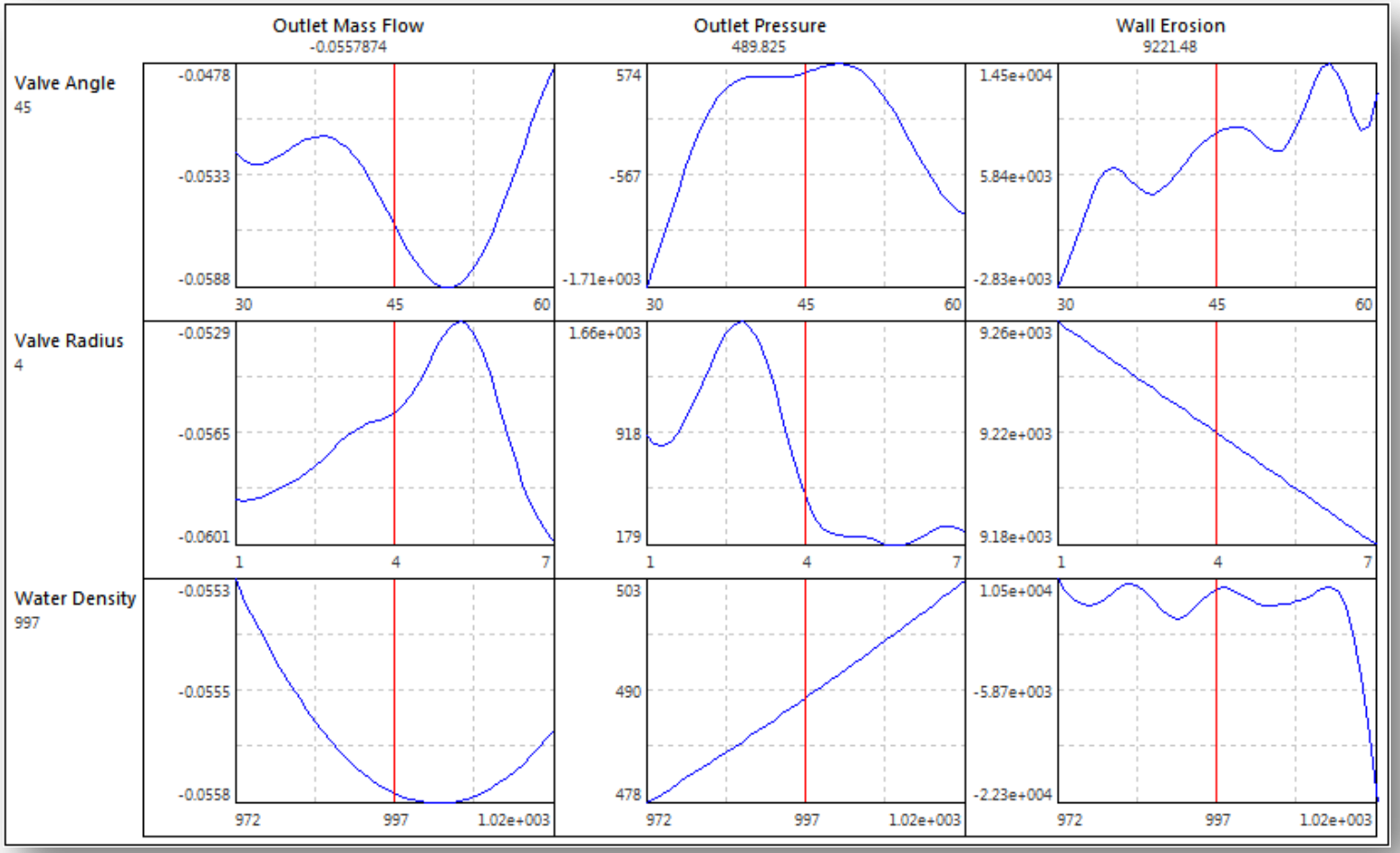
Erosion Density Rate



Outlet Pressure

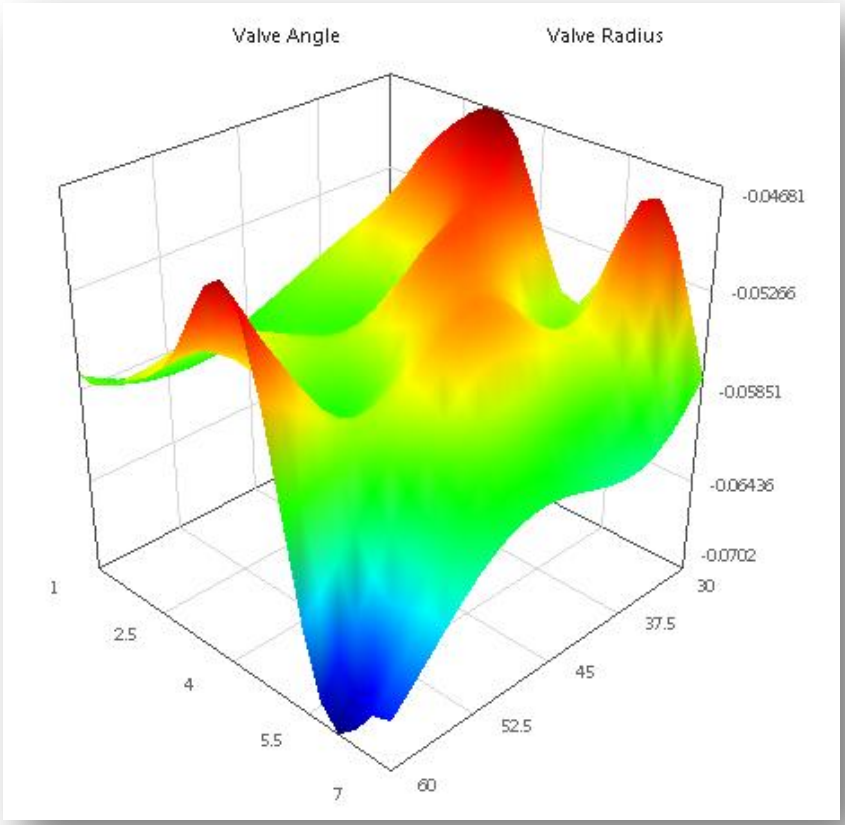


Design Space: 2D Section Diagrams

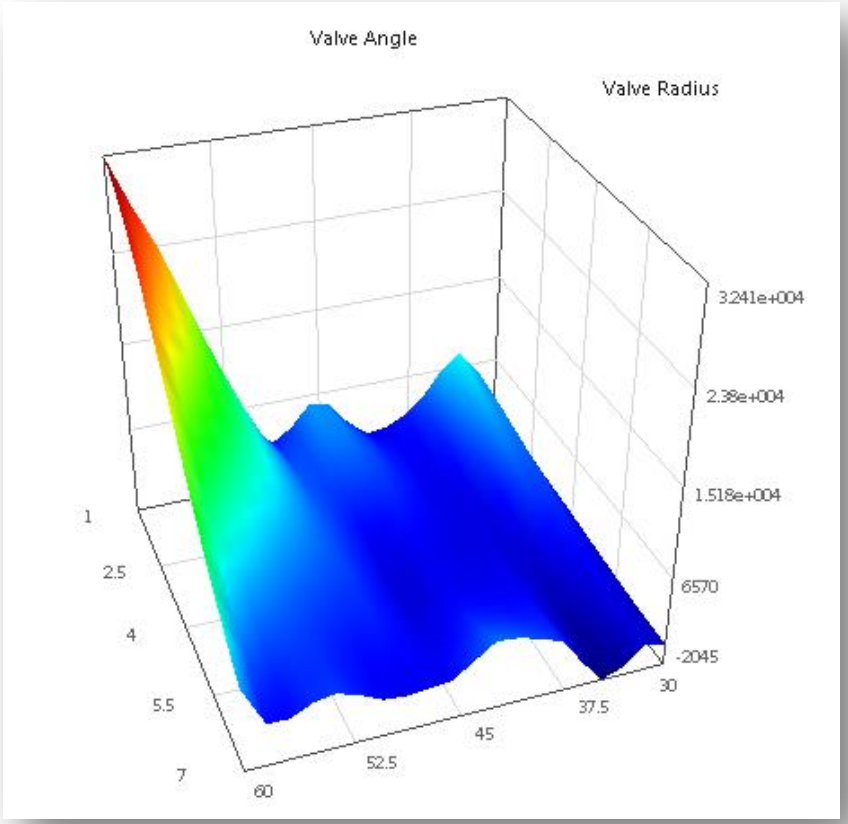


Design Space: 3D Graphics

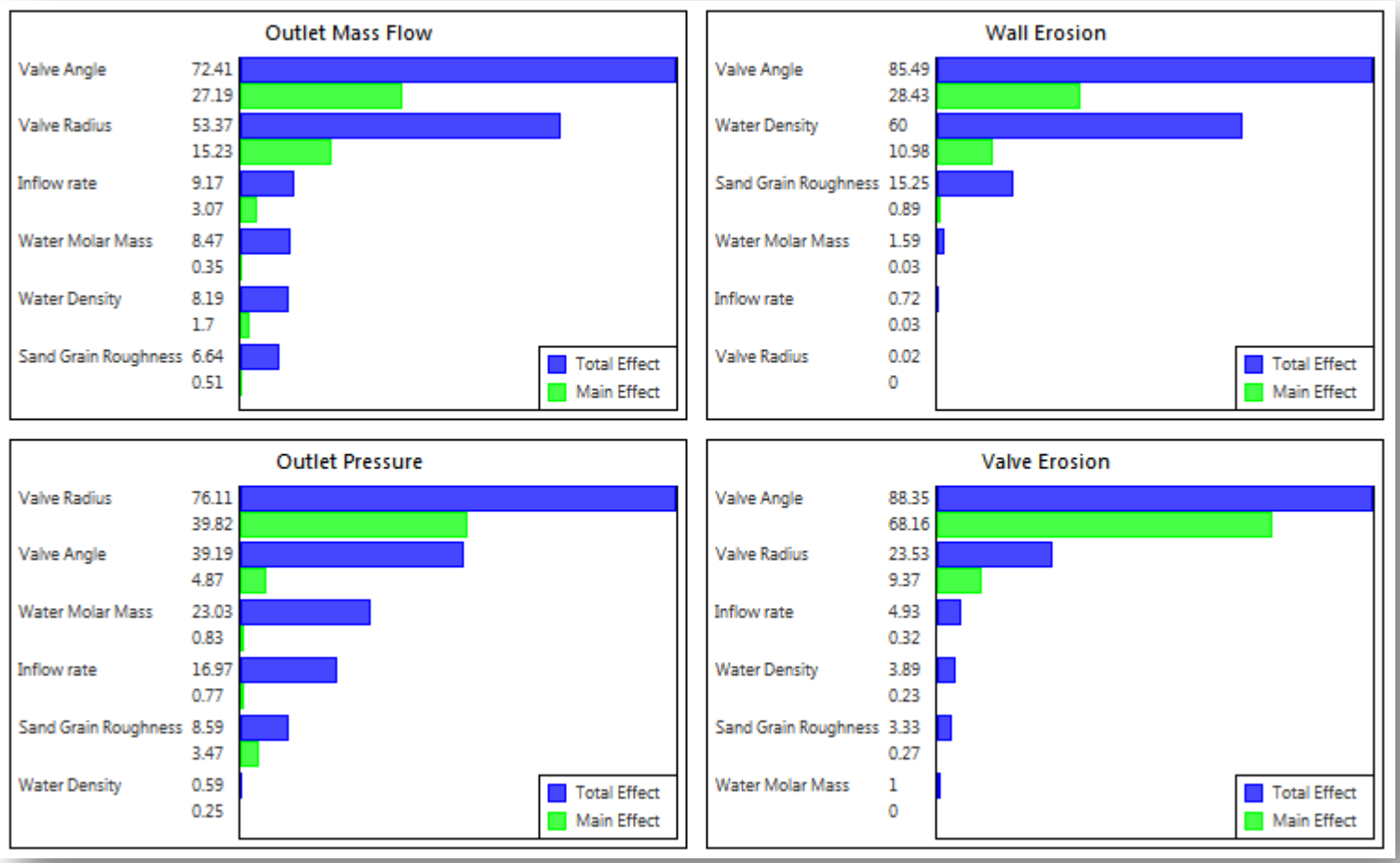
Outlet Mass Flow



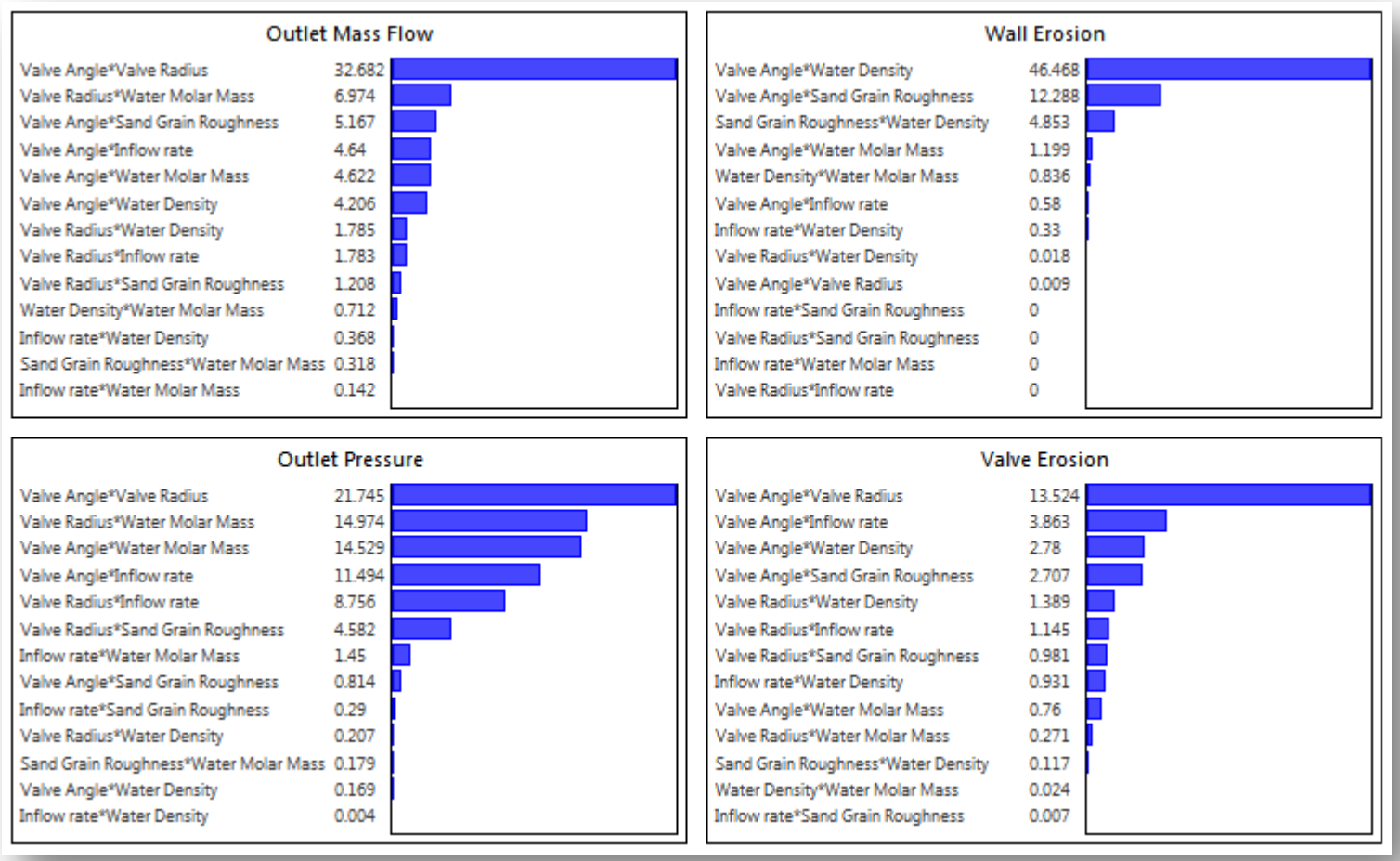
Valve Erosion Density Rate



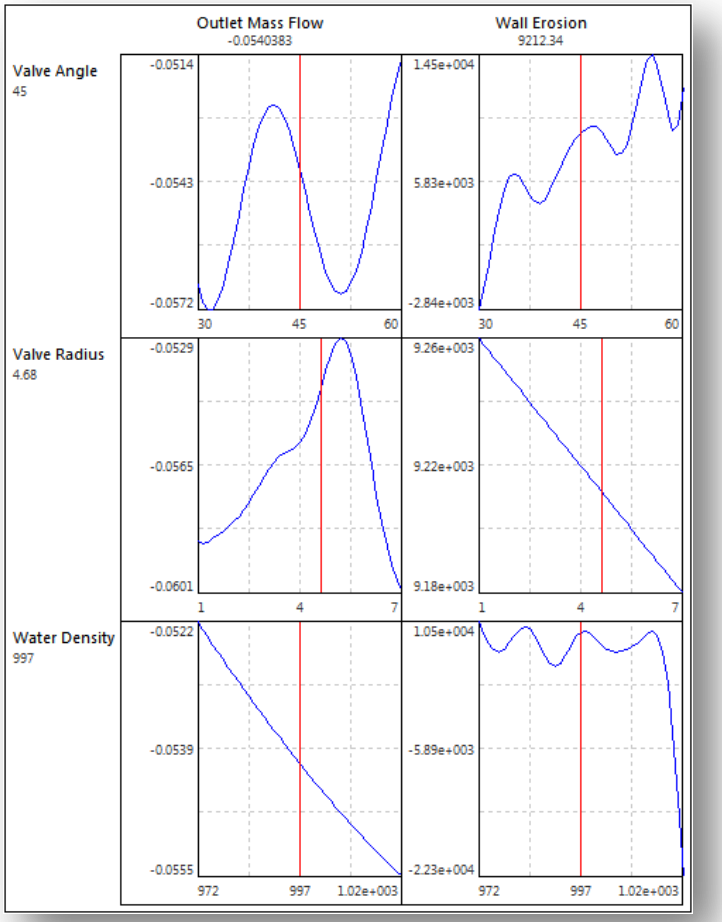
Global Sensitivity: Parameter Importance [%]



Global Sensitivity: Parameter Interaction [%]



Nominal Design Optimization



Optimization Goal:

- Constraint: Outlet Mass Flow [-0.06, 0.054]
- Criteria: Maximize Outlet Pressure, Valve Erosion and Wall Erosion

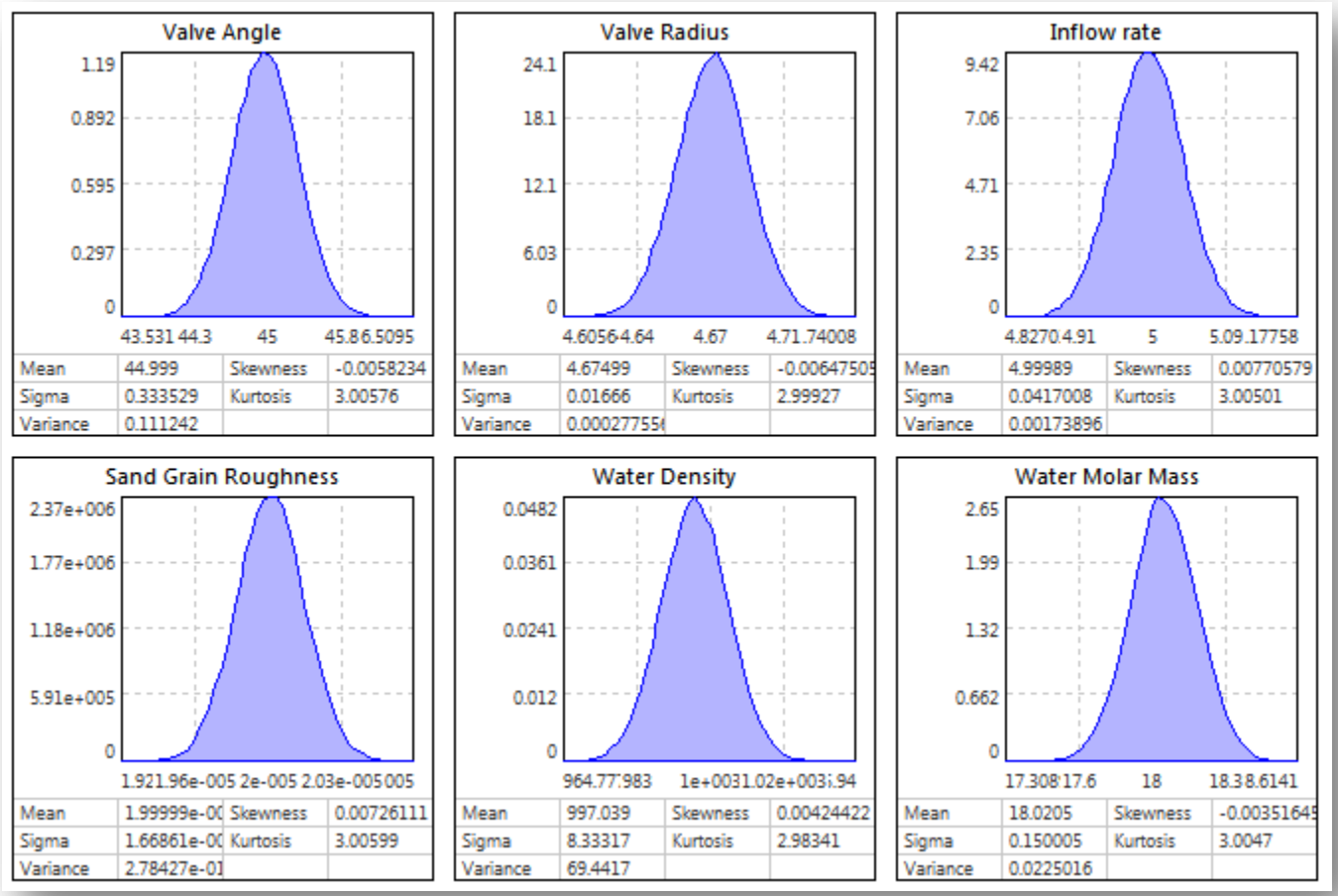
Nominal Design:

- Outlet Mass Flow = -0.05404 kg s^-1
- Outlet Pressure = 244 Pa
- Valve Erosion = 668 kg m^-2 s^-1
- Wall Erosion = 9212 kg m^-2 s^-1

Design Parameters

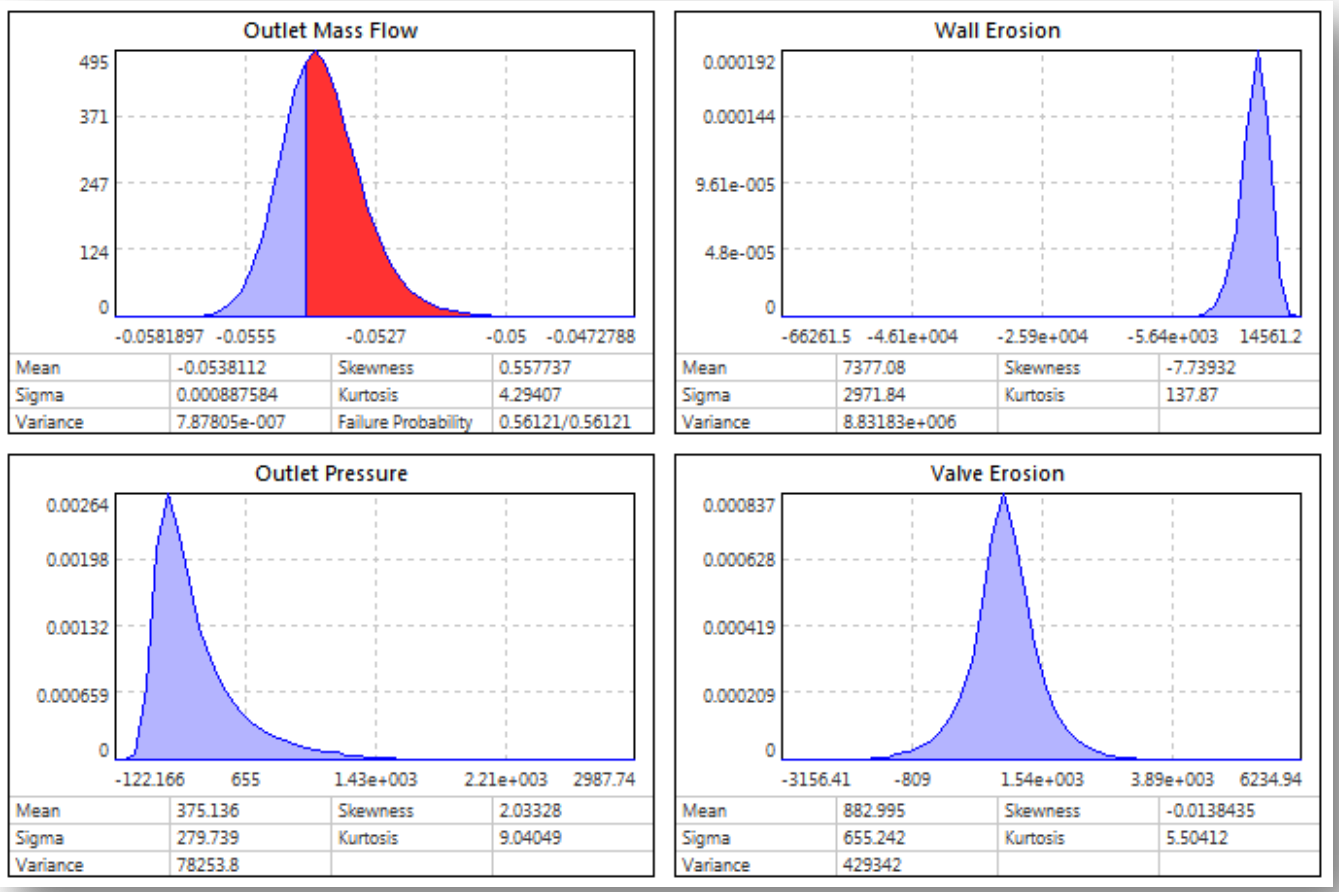
Name	Nominal	Tolerance	Unit
Valve Angle	45	2	deg
Valve Radius	4.675	0.1	mm
Inflow rate	5	0.25	m s^-1
Sand Grain Roughness	2e-005	1e-006	m
Water Density	997	50	kg m^-3
Water Molar Mass	18.02	0.9	kg kmol^-1

Uncertainty Parameters and Tolerances

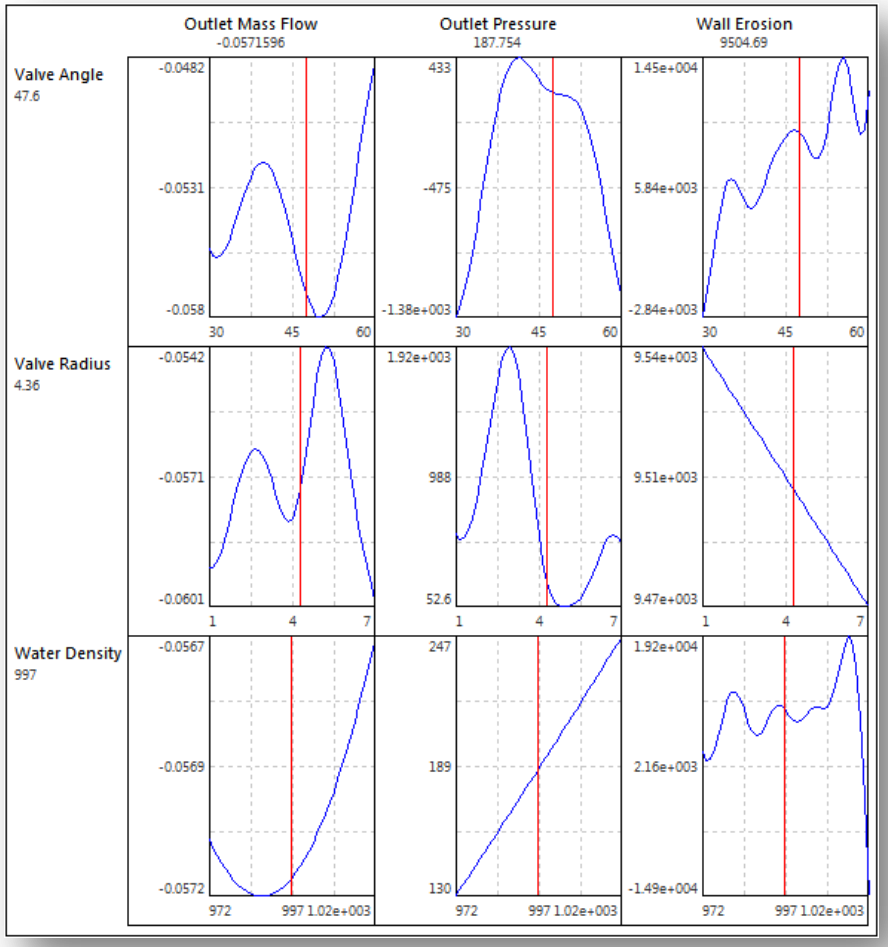


Nominal Design: Reliability Analysis

-0.06 ≤ X ≤ -0.054
Failure Probability = 56,12%



Robust Design Optimization



Optimization Goal for Outlet Flow Rate:
Minimize Taguchi Quality Loss Function

$$L = Cost*(Variance + (Mean - Target)^2)$$

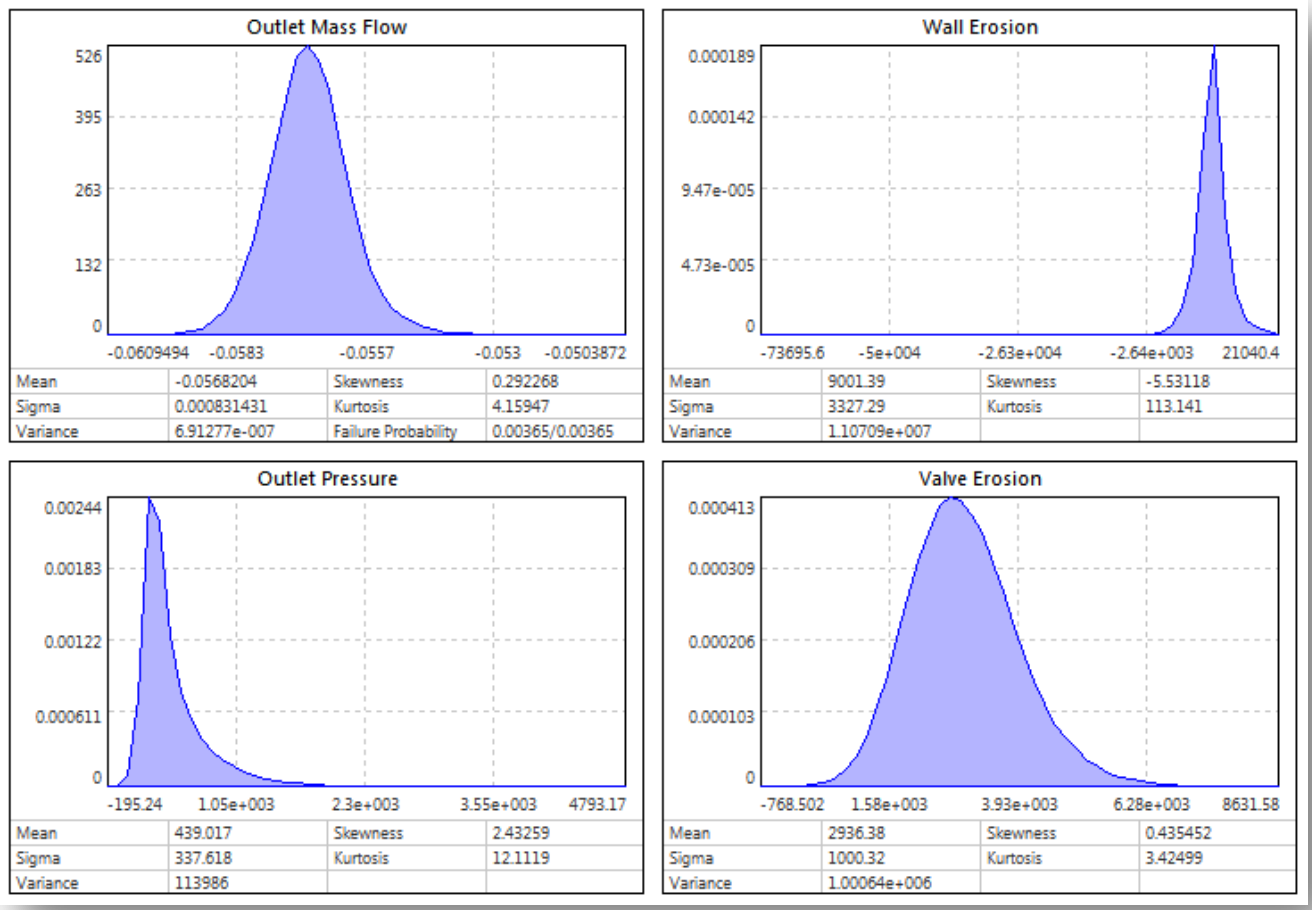
- Cost = 1 Unit
- Target = -0.057 <=> [-0.06, -0.054]

Design Parameters

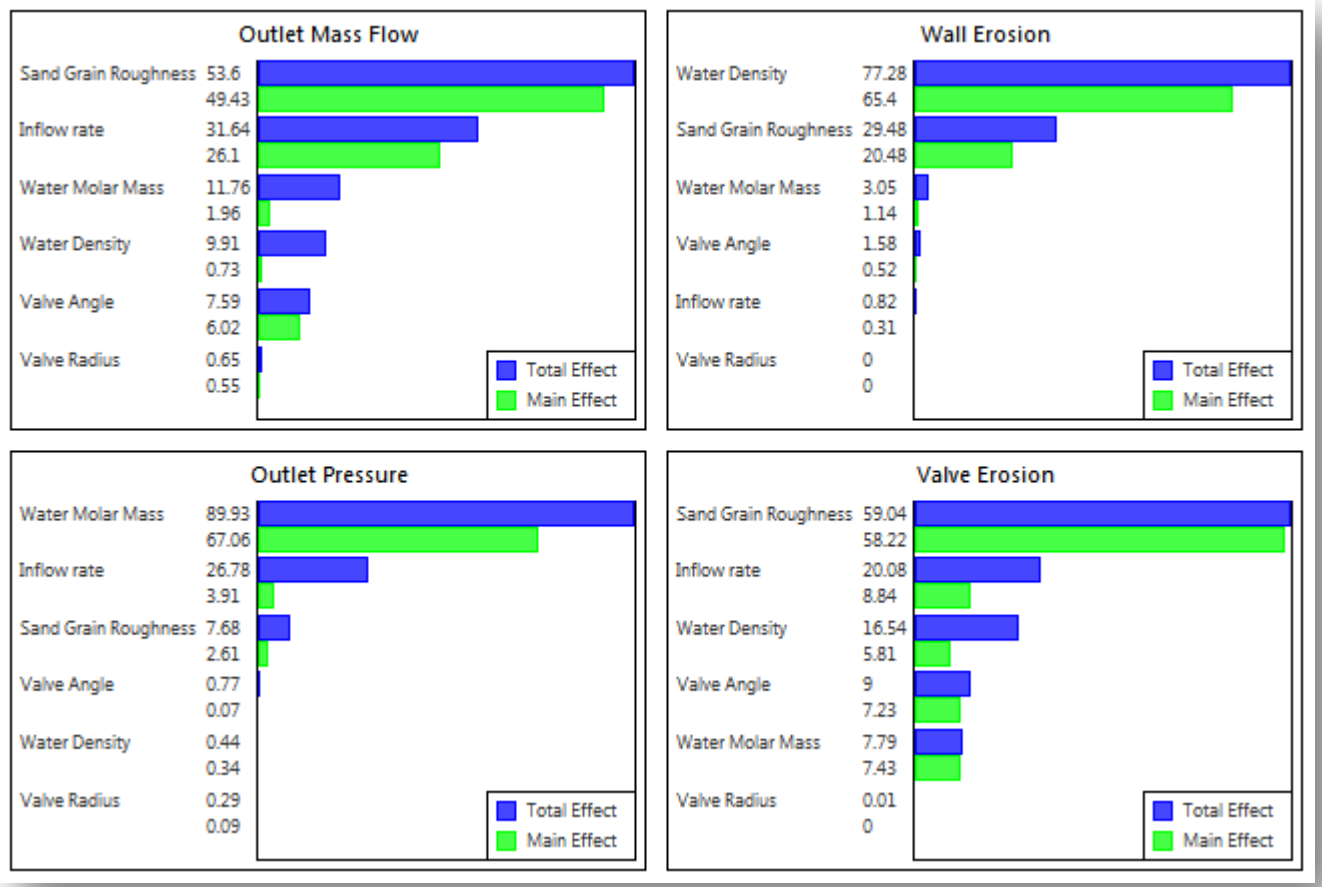
Name	Nominal	Tolerance	Unit
Valve Angle	47.6185325	2	deg
Valve Radius	4.3571066	0.1	mm
Inflow rate	5	0.25	m s^-1
Sand Grain Roughness	2e-005	1e-006	m
Water Density	997	50	kg m^-3
Water Molar Mass	18.02	0.9	kg kmol^-1

Robust Design: Reliability Analysis

-0.06 ≤ X ≤ -0.054
Failure Probability = 0,36%



Robust Design: Design Sensitivity



Conclusion

Nominal design using classical nominal simulation cannot warranty the reliability and quality of the products, because the nominal parameters are only one fix value.

Robust design is a power-full tool for design of reliable and quality product in the early design stage without any cost. It considers the uncertainty parameters as stochastic distributions.

In the case of the butterfly valve, we have got a robust design with 0.36% failure probability for the manufacturing.

OptiY® is the leading software platform for robust design of all engineering fields using different commercial CAD/CAE-software or in-house codes.