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EKATO Gas-Liquid Reaction Technologies

EKATO气液反应技术

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Chlorination in EKATO Photo-Reactors

EKATO光反应器中的氯化

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Photo synthesis

- absorption of light energy (photons) by chlorophyll
- excited electrons, high energy level
- energy transfer and formation of organics, e.g. carbohydrates

Electromagnetic → chemical energy

100 billion tons of biomass / year

光合作用

- 叶绿素吸收光能（光子）
- 激发电子，高能级
- 能量转移和有机物的形成，例如 碳水化合物

电磁 化学能

1000亿吨生物质/年



Target: profitable production by fast reactions with high yield
目标：通过快速反应，高产量实现有利可图的生产

$$r = k \cdot c_A^{x_A} \cdot c_B^{x_B}$$

Kinetics, reaction rate
动力学，反应速率

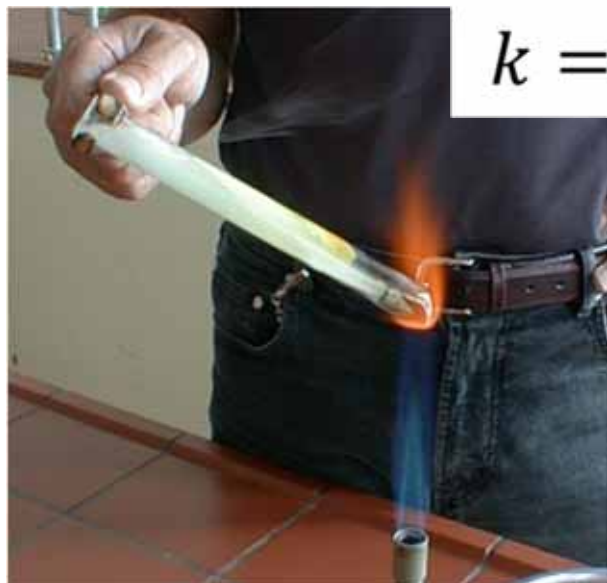
$$k = A \cdot e^{-\frac{E_A}{R \cdot T}}$$

Rate constant, Arrhenius (1889)
速率常数，阿伦尼乌斯（1889）

Why Industrial Photochemistry 为什么选择工业光化学?

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$$k = A \cdot e^{-\frac{E_A}{R \cdot T}}$$



Thermal activation 热激活:

Reaction at 反应在 100 - 250 °C,
Decomposition 分解, by-products 副产品

Catalysts reduce 催化剂减小 E_A :

Cost, handling, separation,
recycling 成本, 处理, 分离, 回收



Photo - activation, 光激活
 $t = 20 - 100 \text{ } ^\circ\text{C}$

Examples of Industrial Photo-Reactions

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Reaction	Product	Multi phase
Chlorination Bromination	Intermediates, Solvents, Rubbers, Polymers (e.g. C-PVC)	l, l-g l-g-s
Sulfoxidation	Sulfonic acids, Intermediates, Surface active materials	l-g
Sulfochlorination	Sulfochlorids, Intermediates, Surface active materials	l-g
Nitrosylation	Oximes, Intermediates, Nylon - types	l-g-s
Oxidation	Intermediates, Surface active materials	l, l-g l-g-s
Isomerization	Intermediates	l
Cycloaddition	Intermediates	l
Polymerization	Polymers	l, l-s, g-s

Agitated reactor
 搅拌反应器,
 ideal for 2 / 3 - phase
 systems
 l - s - g
 2/3相系统的理想选择

Examples of Industrial Photo-Reactions

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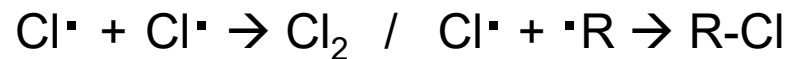
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Process 工艺	Product 产品	Industry 行业	多相 (液-气-固)
Chlorination 氯化	中间体, 溶剂 C-PVC, 橡胶	特殊化学品, 聚合物	液-气 液-气-固
Bromination 溴化	中间体	特殊化学品, 消费品	液
Sulfoxidation 磺化氧化	中间体, 松香酸 表面活性材料	特殊化学品, 消费品 聚合物	液-气
Sulfochlorination 氯磺化	中间体, 松香酸 表面活性材料	特殊化学品, 消费品 聚合物	液-气
Nitrosylation 亚硝基化	中间体 尼龙 6 & 12	特殊化学品, 聚合物	液-气-固
Oxidation 氧化	中间体 表面活性材料	特殊化学品 香料, 药品	液 液-气 液-气-固
Isomerization 异构化	中间体	特殊化学品 药品	液
Cycloaddition 环加成 Electrocyclic Reaction 电环化反应	中间体	特殊化学品 药品	液
Polymerization 聚合	聚合物	特殊化学品 聚合物	液 液-气 液-气-固

Agitated reactor
搅拌反应器,
ideal for 2 / 3 - phase
systems
l - s - g
2/3相系统的理想选择

Example chlorination for intermediates or chlorinated polymers**中间体或氯化聚合物的示例**

Chain termination by recombination of radicals 通过自由基重组链终止



Industrial Photo-Chemistry 工业光反应

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Agitated tank reactors:

- Tank volume 2 to 50 m³
- UV- lamps in protective glass tubes (quartz, borosilicate)
- Agitator
 - blending, transport to radiation source
 - gas dispersion, mass transfer
 - solids suspension
 - heat transfer
- Corrosion resistant MOC

搅拌釜反应器：

- 容器容积2至50立方米
- 防护玻璃管中的紫外线灯（石英，硼硅酸盐）
- 搅拌器
 - 混合，运送到辐射源
 - 气体分散，传质
 - 固体悬浮液
 - 传热
- 耐腐蚀MOC

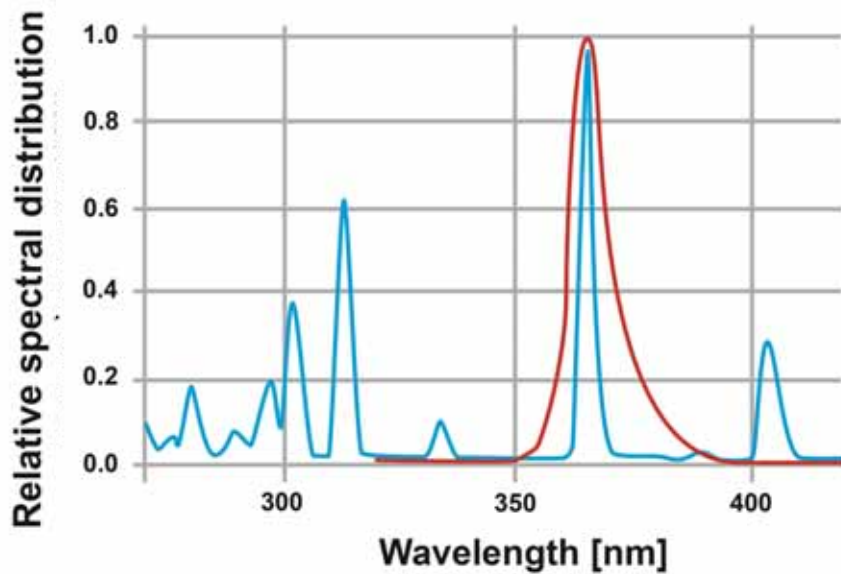


- UV light source – emission spectrum:
紫外线光源-发射光谱
- wavelength of absorption and excitation of chromophores
载色体的吸收和激发波长
- Photon flux, quantum yield Y
光子通量, 量子产率

$$Y = \frac{r}{i} \left[\frac{\text{mol}}{\text{mol}} \right]$$

- Determination of absorption coefficients
吸收系数的确定





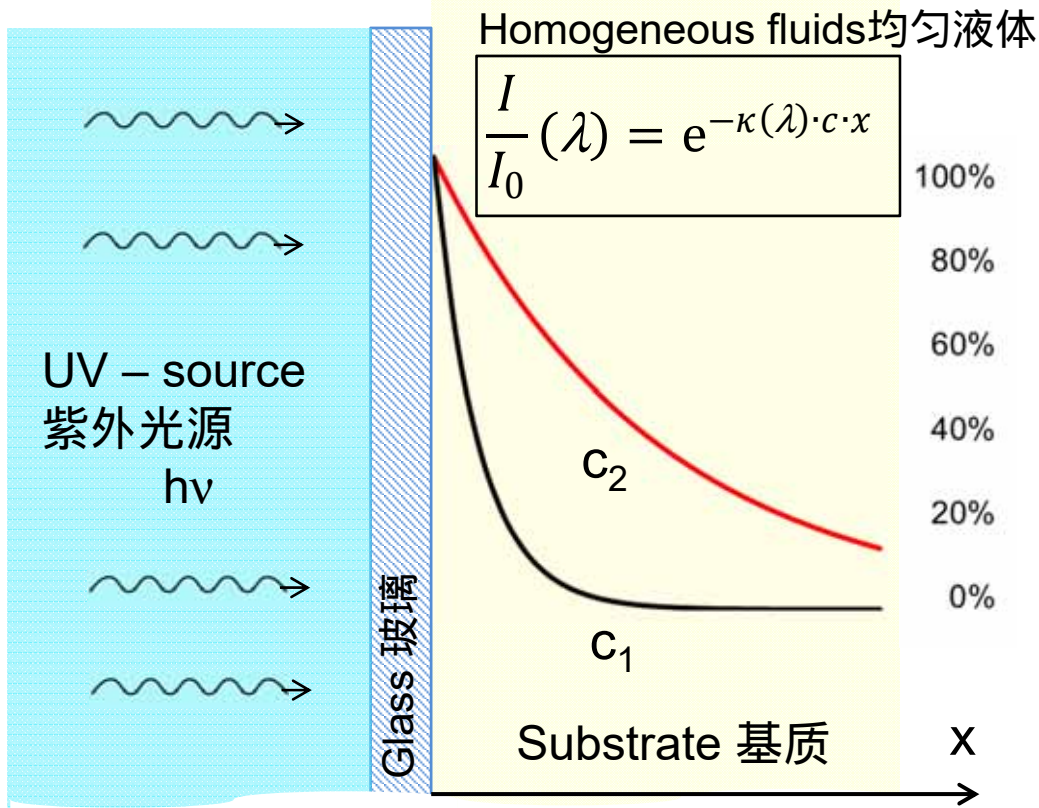
Hg-arc 汞弧

- Broad spectrum 广谱
- High temperature 高温 ($\leq 900\text{ }^{\circ}\text{C}$)
- 360 ° - radiation 辐射

LED

- Monochromatic, exact fit to absorption spectrum 单色, 完全适合吸收光谱
- Low temperature, cooling needed 低温, 需要冷却
- Radiation unidirectional in sectors 扇区中的单向辐射
- Current development for full scale (power-/temperature control, long term stability etc.)

全尺寸开发 (功率/温度控制, 长期稳定性等)



$\kappa(\lambda)$ molecular-specific absorption coefficient
分子吸收系数

Concentration 浓度 $c_1 > c_2$

$x_{0,2}$ up to 100 mm

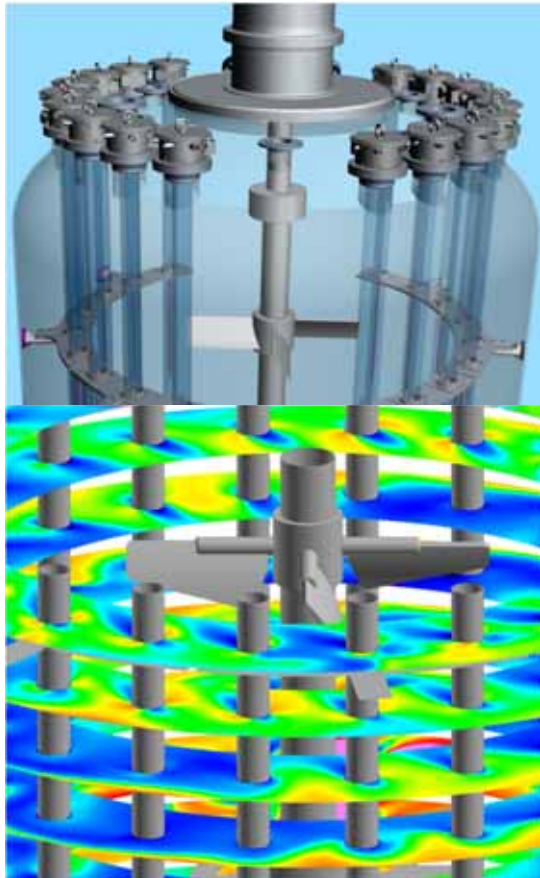
Heterogeneous systems:
additional absorption, reflection
and scattering coefficients

异构系统：附加的吸收，反射和散射系数

Reaction yield: irradiation 反应产率：辐照

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- - V_j : number of lamps 灯数量 (max. 20), L, D
- - Power of lamps 灯功率 (I_0): e.g. Hg-arc lamps 汞弧灯
 $P_{el} = 5$ to 60 kW each 每只

- - Contact substrate – photons at the lamp well
接触基材–灯壁处的光子

$$\frac{Z}{t} \propto \dot{q} \propto \frac{1}{\theta} \propto n \propto P^{1/3}$$

$$\frac{Z}{t} \propto D^{4/3} \quad P = \text{const.}$$

Optimization of impeller flow combined with tank internals 与容器内构件一起进行桨叶流型的优化(CFD)

Reaction yield 反应产出: mass transfer 传质 g - l, heat transfer 传热

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EKATO test center, 30 m³ tank

$$\dot{m} = k_L a \cdot (c^* - c) \quad k_L a = c_1 \cdot c_2 \cdot \left(\frac{P}{V} \right)^x \cdot v_{sg}^y$$



Combined Gassing 组合加气:
recirculation increases v_{sg}
再循环增加

Reaction heat 反应热, wall and cooling coils 容器壁和盘管:
 $Nu = f(Re, Pr, Geo)$ or by CFD

Lamp installation 灯泡的安装

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Standardized lamps and modular heads 标准化灯和模块化安装头 :

- feed through of electric power, cooling medium 通电和冷却介质
(arc temperature 弧温 $\leq 900\text{ }^{\circ}\text{C}$, cooling by water or N_2 由水或 N_2 冷却)
- HAZOP: glass breakage monitoring 玻璃破碎监测 \rightarrow containment control 控制



Peschl Ultraviolet

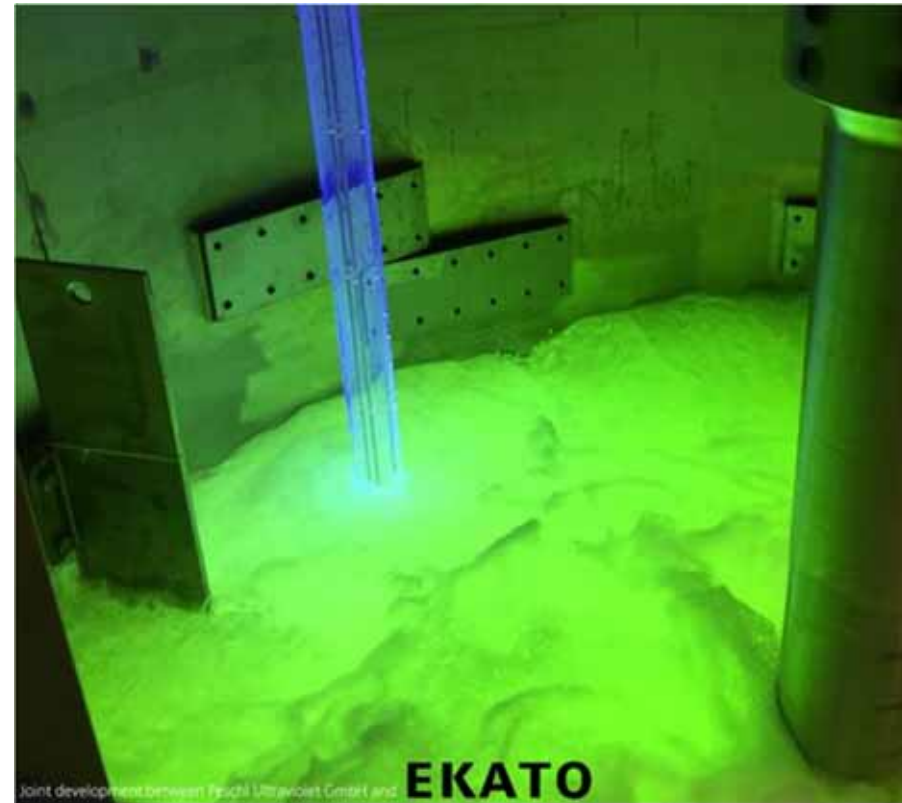
Quartz-tubes and supports 石英管和支架

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- Typical size 典型尺寸: DN 100, 6 – 8 m long
- Support without gap and stress free
支撑无间隙和无应力
- Stress free thermal dilatation 无应力热膨胀
Medium to vigorous mixing 中度到剧烈混合,
 $P/V = 0,5 \text{ to } 4 \text{ kW/m}^3$
- Dynamic pressure load 动态压力载荷

$$\Delta p = c_w \cdot \frac{\rho \cdot v^2}{2} \pm \phi$$



Model testing, 1 lamp / quartz tube, 30 m³ tank

Quartz-tubes and supports 石英管和支架

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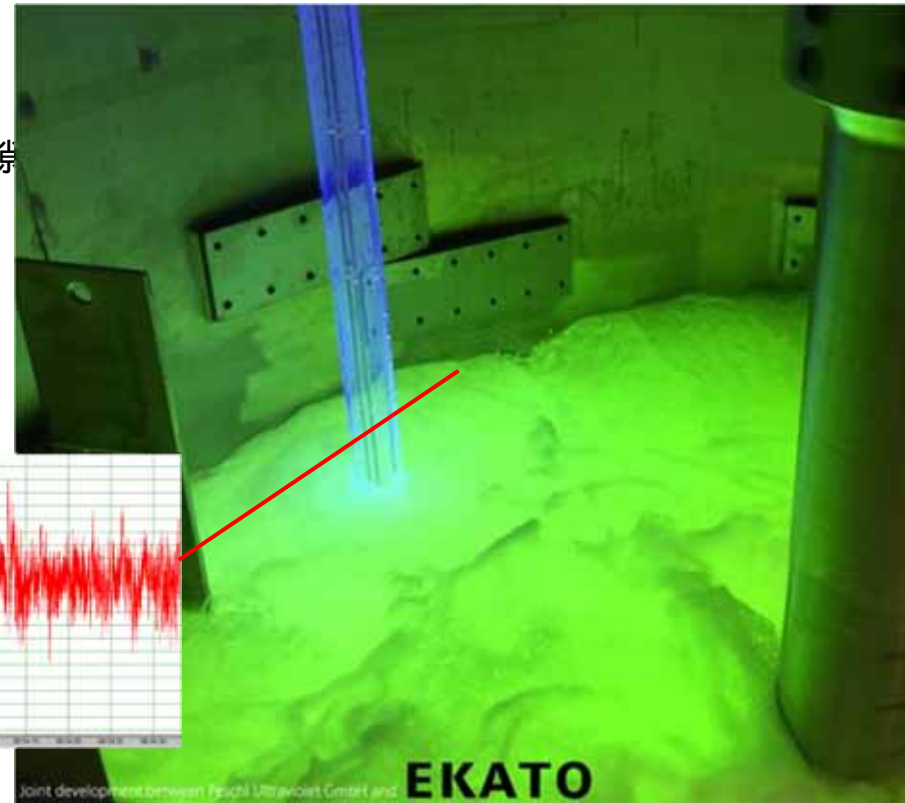
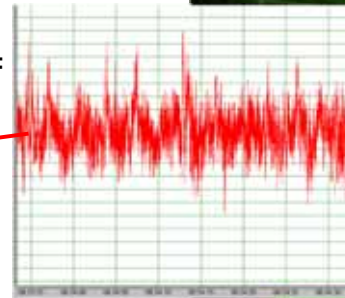
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- Typical size 典型尺寸: DN 100, 6 – 8 m long
- Support stress free and no gap 支撑无应力和间隙
- Stress free thermal dilatation 热膨胀无应力

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- Dynamic pressure load 动态压力载荷

$$\Delta p = c_w \cdot \frac{\rho \cdot v^2}{2} \pm \phi$$



Model testing 模型试验, 1 lamp / quartz tube 石英管, 30 m³ tank

Quartz-tubes and support: vibration, resonance 石英管和支架：振动，共振

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Vibration excitation 振动激发:

- Stochastic 随机的:
high energy turbulent vortices with 高能湍流涡流 $f < 10$ Hz
- Periodic 周期的:
blade passing frequency 桨叶通过频率 $f = n \cdot z$

vortex shedding 旋涡分离; (Karman) $f = \frac{Sr \cdot v}{d}$

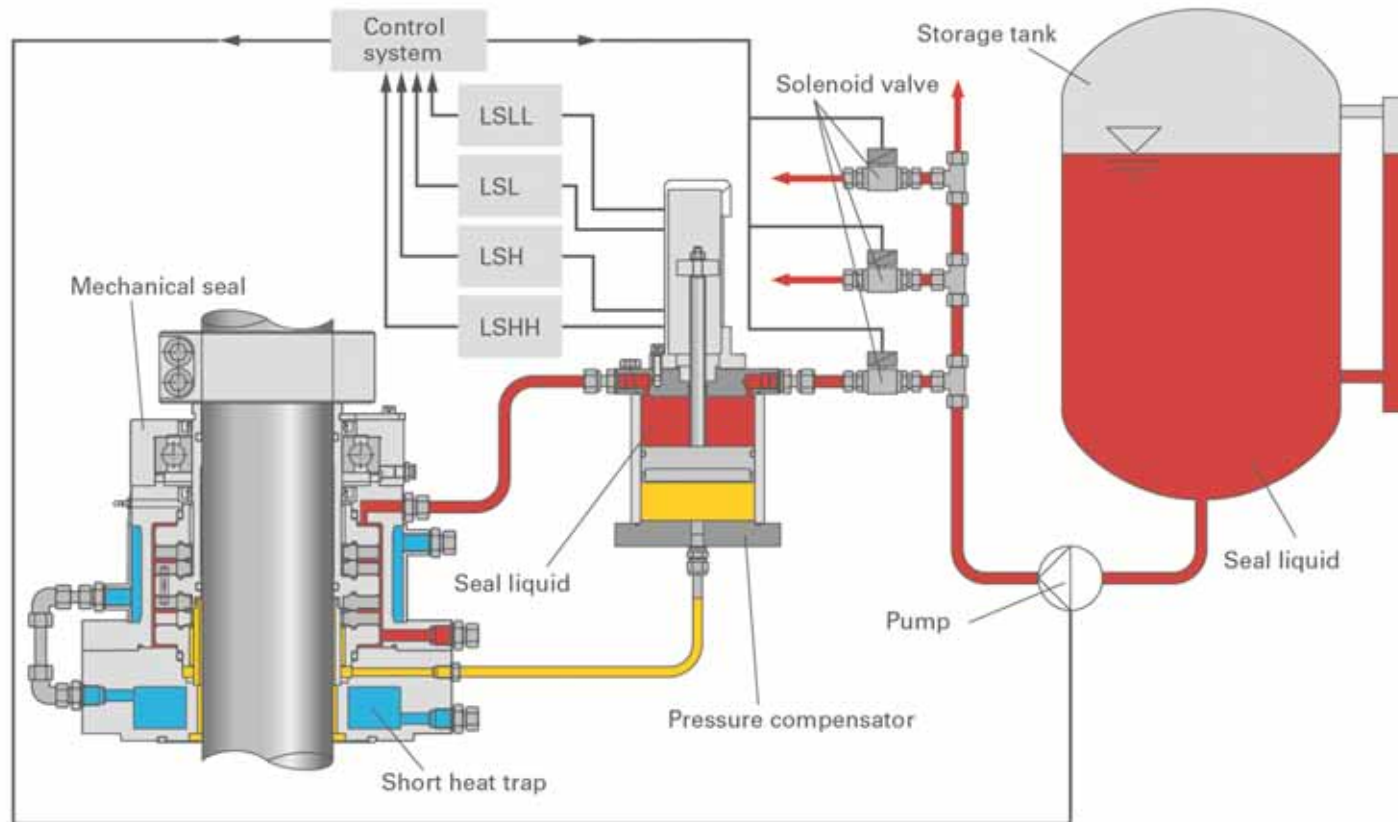
Design 设计: $f_n \gg f_e$

Calculation of f_n 计算: FE-analysis 分析, consideration of fluid - structure interaction 考虑流体-结构相互作用

Reliable operation: double acting mechanical seals 可靠的操作：双端面机械密封

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Thank you for your attention!

感谢您的关注！

