# Packing Characterization-Mass Transfer Properties

Chao Wang
Carbon Management Project of PSTC
Advisors: Gary Rochelle and Frank Seibert
Research Engineer: Micah Perry
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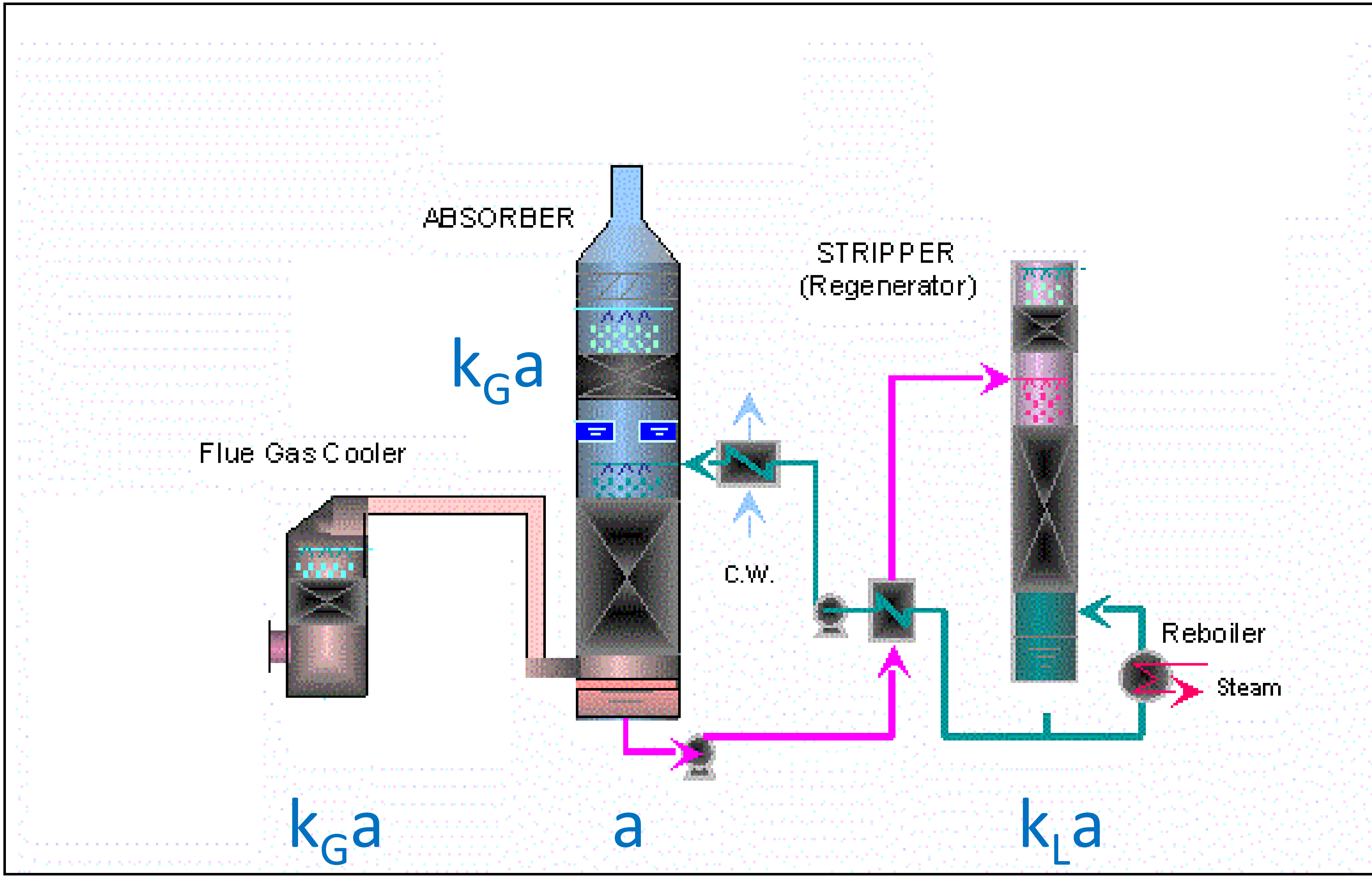
# Mass Transfer in a Typical $CO_2$ Capture Process



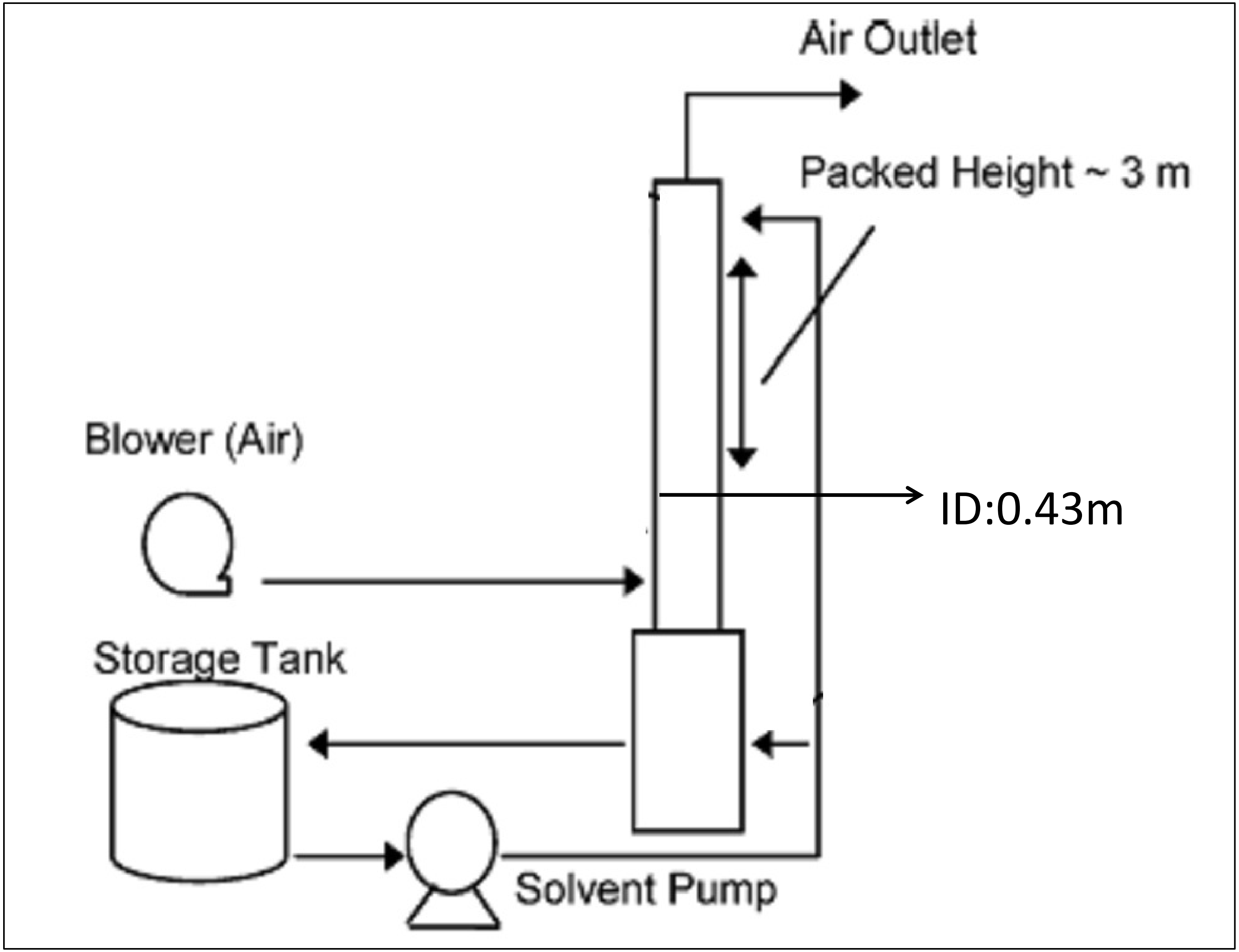

$$\frac{1}{K_G a} = \frac{1}{k_G a} + \frac{H_{CO2}}{a\sqrt{k_2[Am]D_{CO2}}} + \frac{1}{k_l a}\left(\frac{\Delta P_{CO2}}{\Delta c_{CO2}}\right)^*$$

# Research objective

- $a_e$—effective gas-liquid contact area--$CO_2$ capture absorber
- $k_G a$–gas film mass transfer coefficient– water wash, gas cooler
- $k_L a$– liquid film mass transfer coefficient–stripper

- Objective: -measure $a_e$, $k_G$ and $k_L$ for novel structured and random packings
- - develop a fundamental model can predict $a_e$, $k_G$ and $k_L$ for novel packings.

# Packed Column



# Packing Information

| Packing Name | RSP 250 | FP 1.6 Y HC | Mellapak 2X | RSR #0.5 | 1” Plastic Pall Ring |
|---|---|---|---|---|---|
| Type | Hybrid | High Capacity | 60° angle | Random metal | Random plastic |
| Surface Area ($m^2/m^3$) | 250 | 295 | 205 | 250 | 210 |
| Corrugation Angle | N/A | 45 | 60 | N/A | N/A |
| Channel Side, S (m) | N/A | 0.017 | 0.02 | N/A | N/A |
| Void fraction, ε | 0.92 | 0.95 | 0.99 | N/A | N/A |

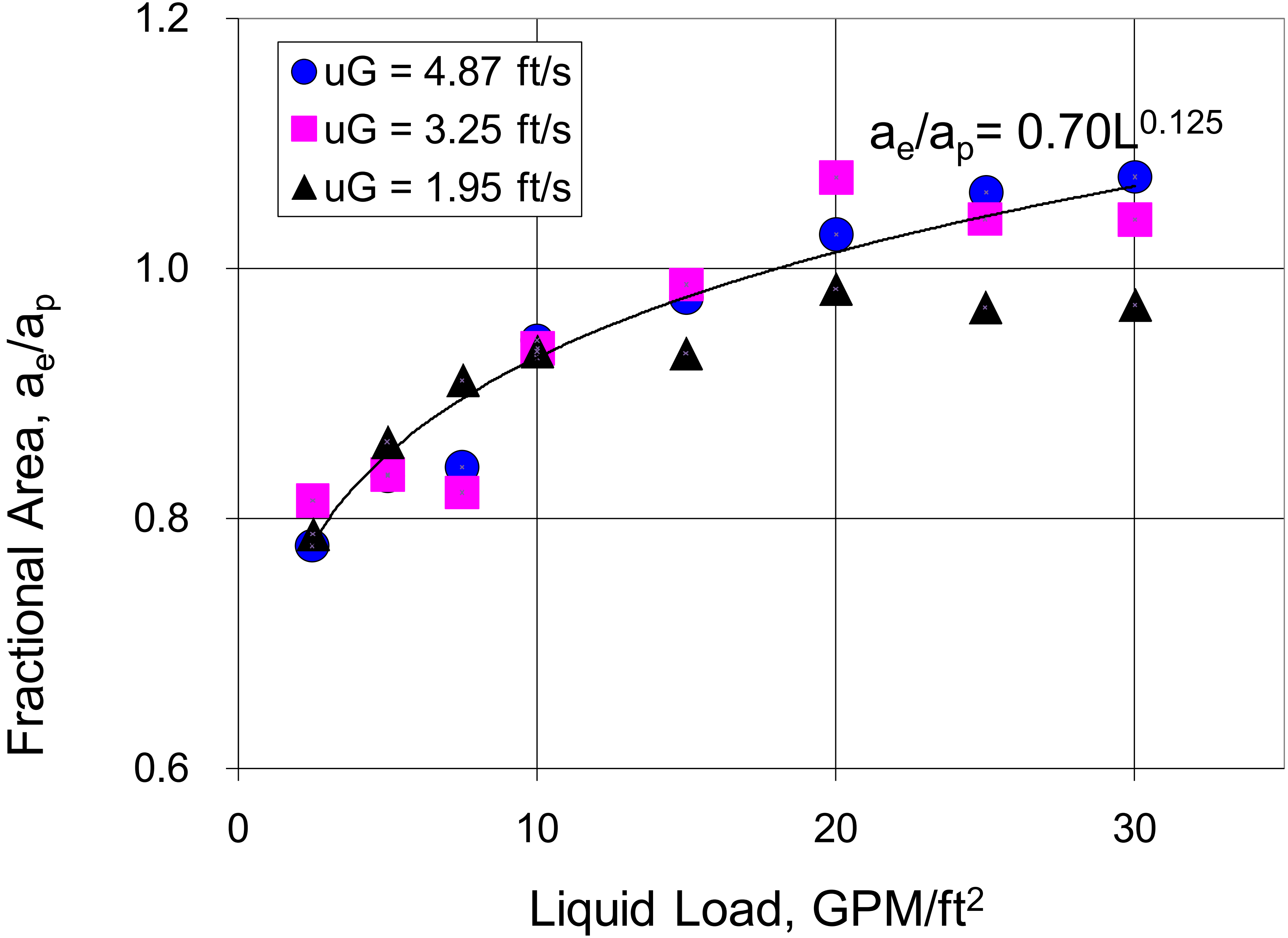
# Effective gas-liquid contact area

- Absorption of $CO_2$ into 0.1 N NaOH solution
- Pseudo first order reaction
- Liquid phase control

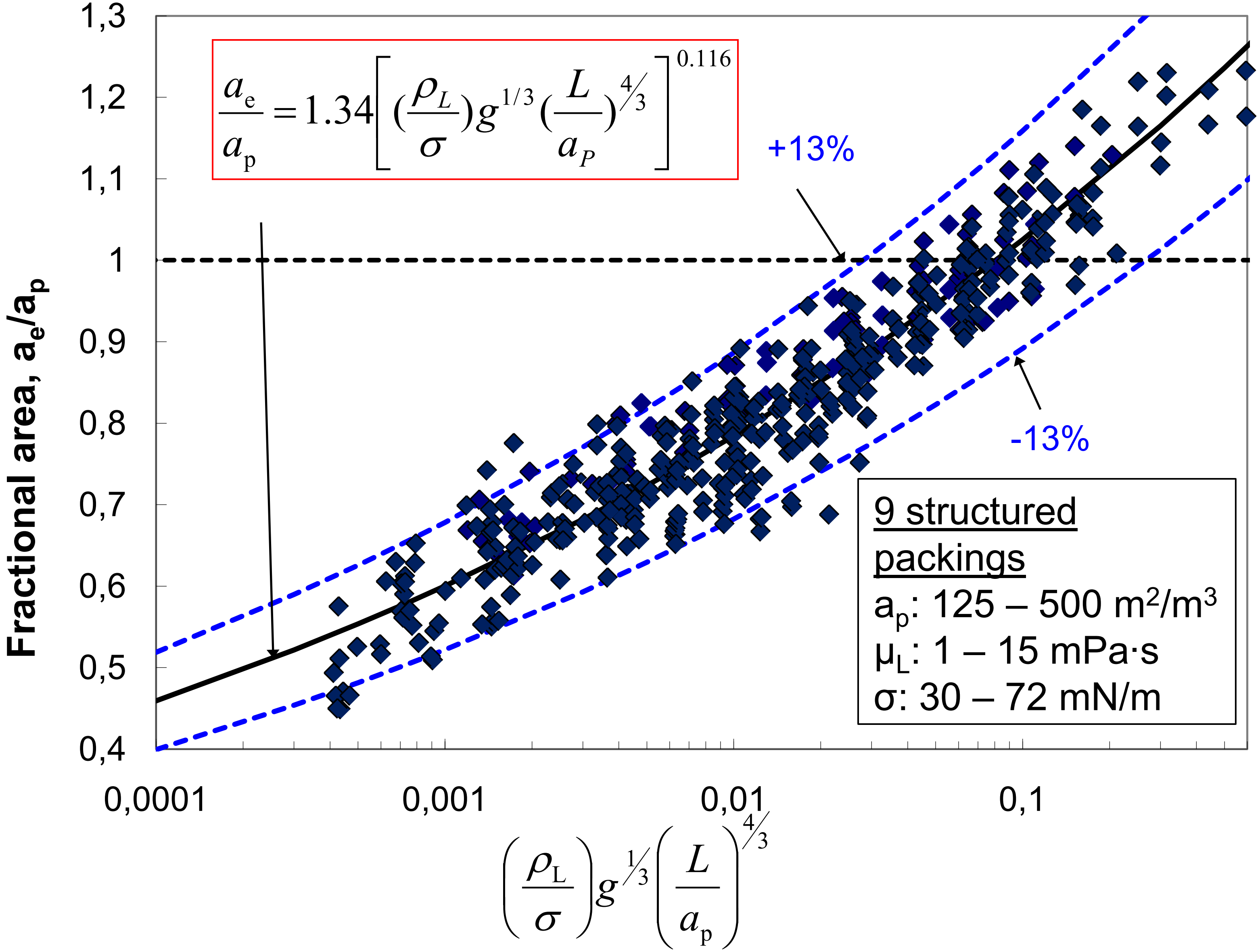
$$a_e = \frac{u_G \ln(\frac{y_{CO_2 in}}{y_{CO_2 out}})}{ZK_G RT} \approx \frac{u_G \ln(\frac{y_{CO_2 in}}{y_{CO_2 out}})}{Zk_G^{'} RT}$$

$$k_g^{'} = \frac{\sqrt{k_{OH^-}[OH^-]D_{CO2,L}}}{H_{CO2}}$$

# Gas-liquid contact area of MP2X

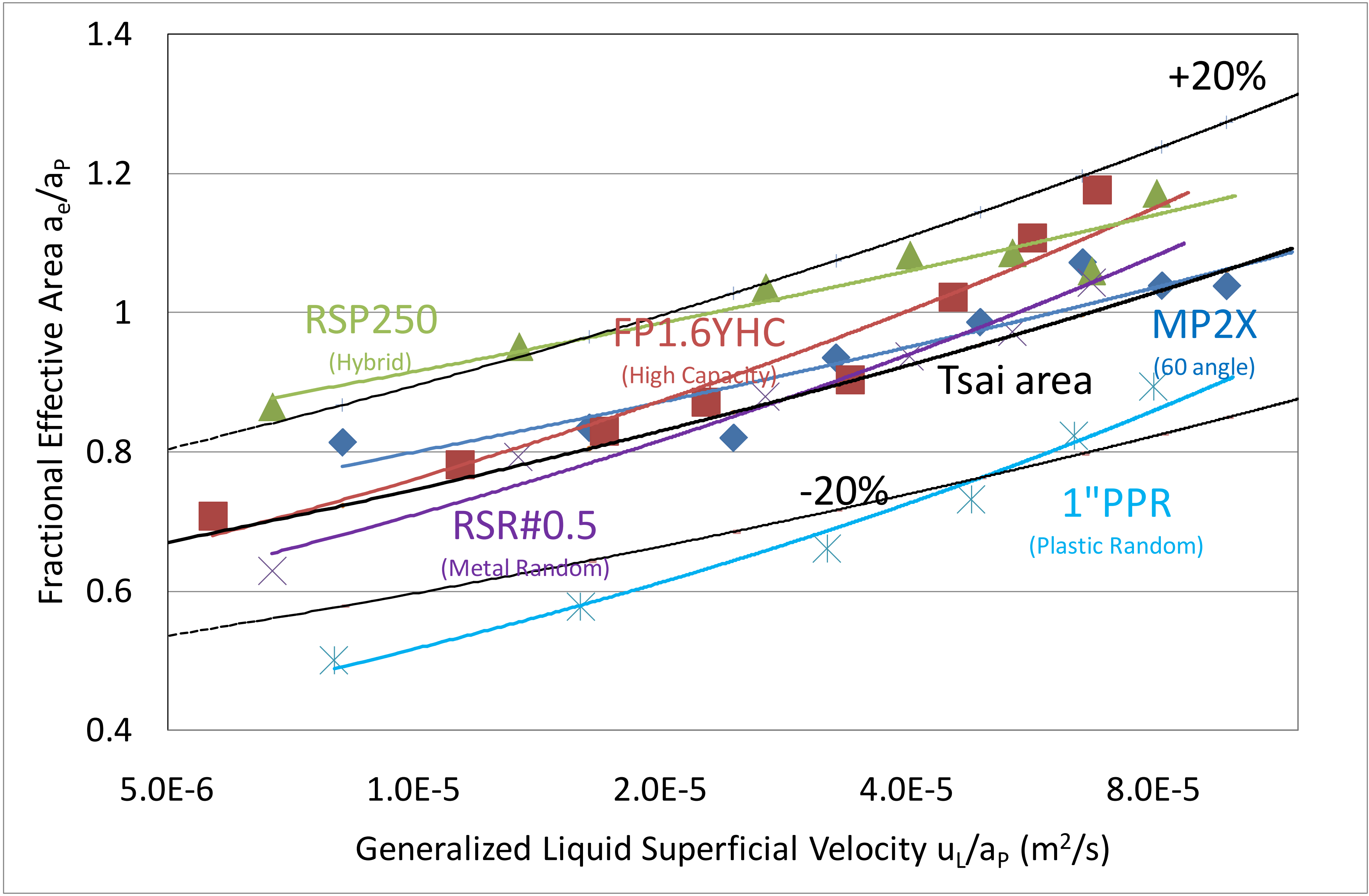


# Tsai's area model (Tsai,2010)




Tsai R. *"Mass Transfer Area of Structured Packing".* The University of Texas at Austin. Ph.D Dissertation. 2010

# Gas-liquid contact area



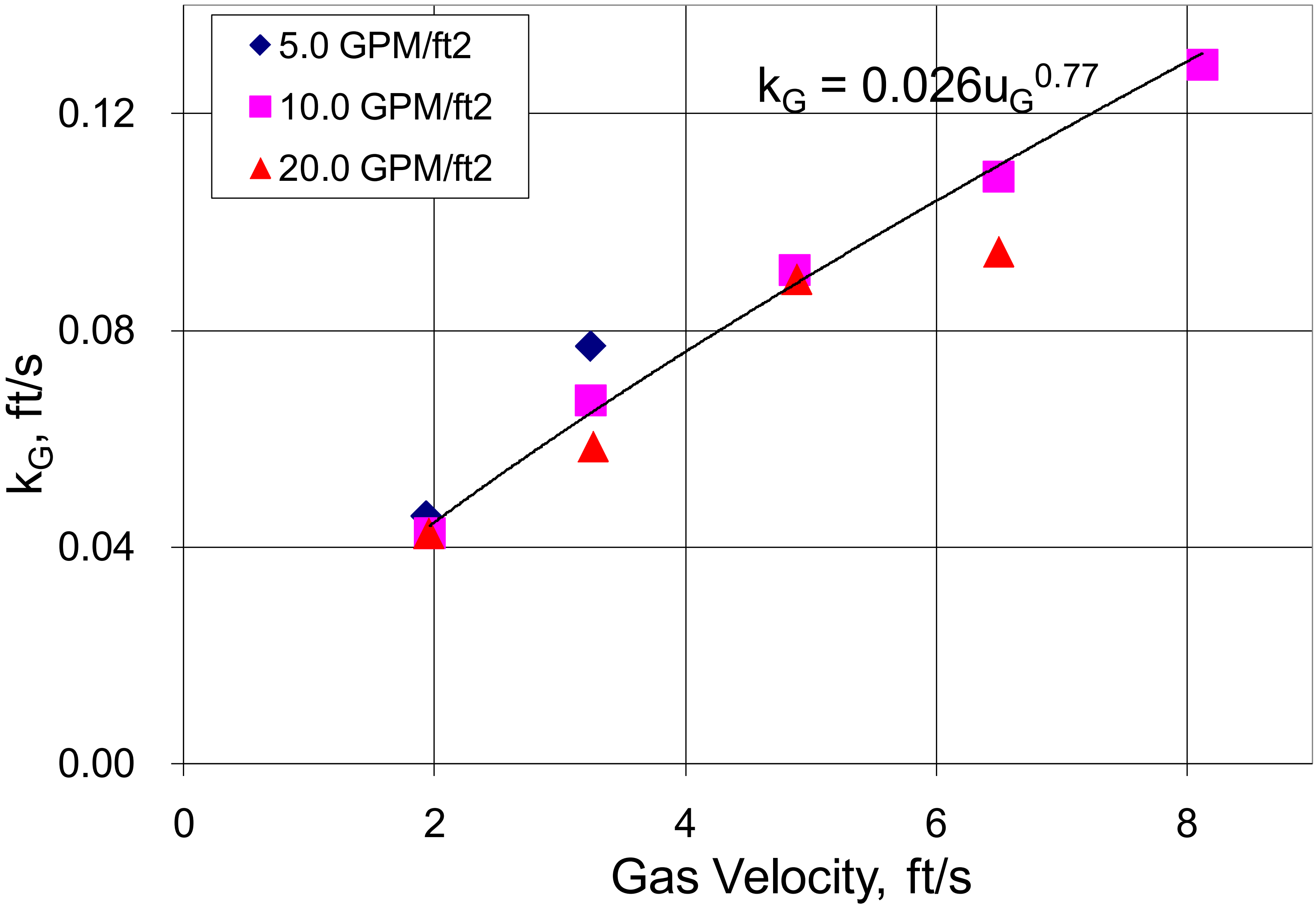
# Gas Film Mass Transfer Coefficient

- Gas film control ($SO_2$/NaOH solution system)
- Instantaneous reaction
- Liquid film resistance can be neglected

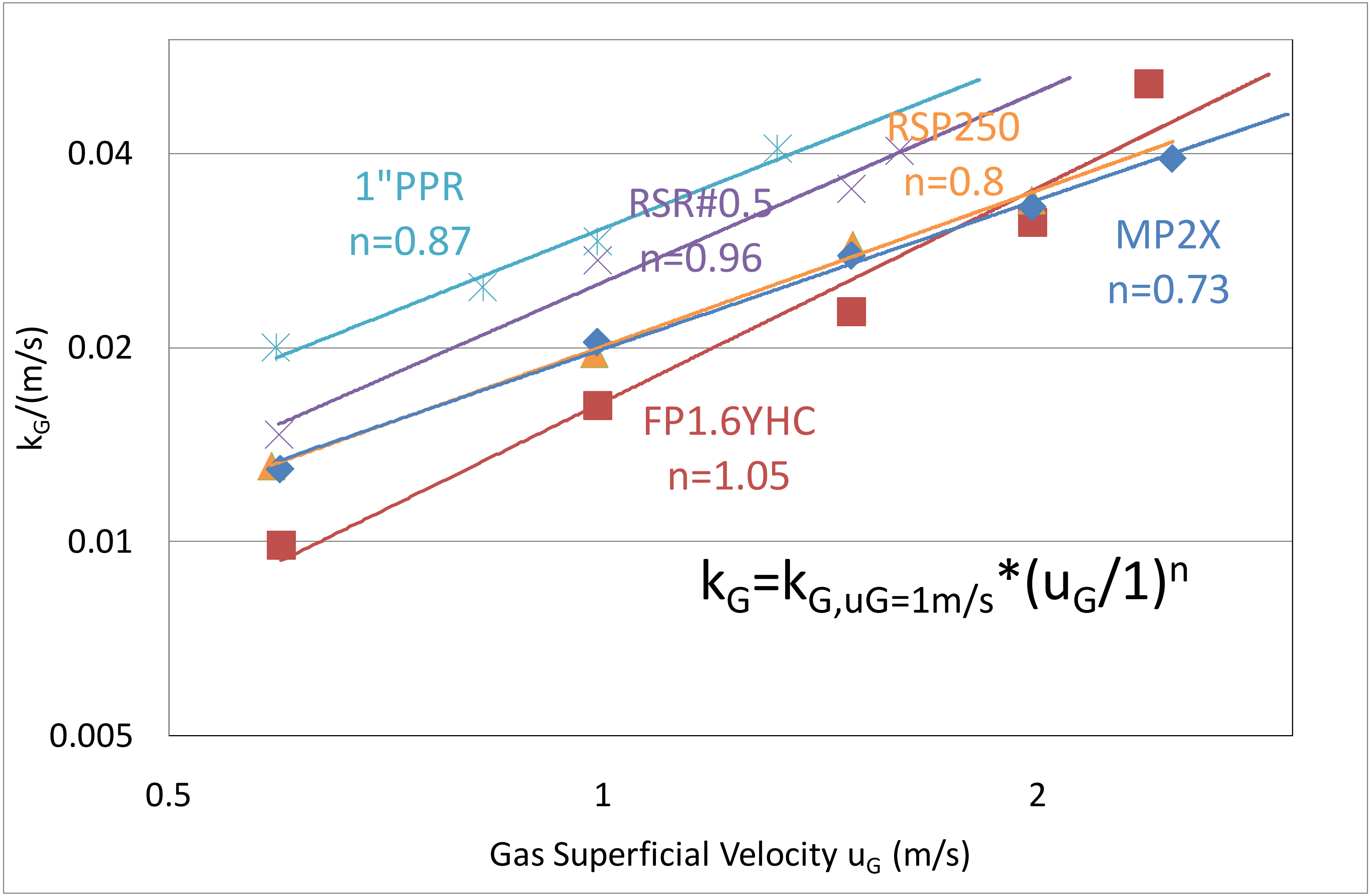
$$k_G a = \frac{u_G \ln\left(\frac{y_{in}}{y_{out}}\right)}{ZRT} \qquad k_G = \frac{k_G a}{a_e}$$

- $SO_2$ concentration is measured by two different range $SO_2$ analyzers. Outlet sample $SO_2$ analyzer can detect 0.1 ppb $SO_2$ $\longrightarrow$ can use 10 feet packing

# Gas film mass transfer coefficient $k_G$ of MP2X



# $k_G$ summary



1"PPR
n=0.87
RSR#0.5
n=0.96
RSP250
n=0.8
MP2X
n=0.73
FP1.6YHC
n=1.05
$k_G=k_{G,uG=1m/s}*(u_G/1)^n$
0.04
0.02
0.01
0.005
0.5
1
2
$k_G$/(m/s)
Gas Superficial Velocity $u_G$ (m/s)

# Modified Rocha-Bravo-Fair[1] $k_G$ Model

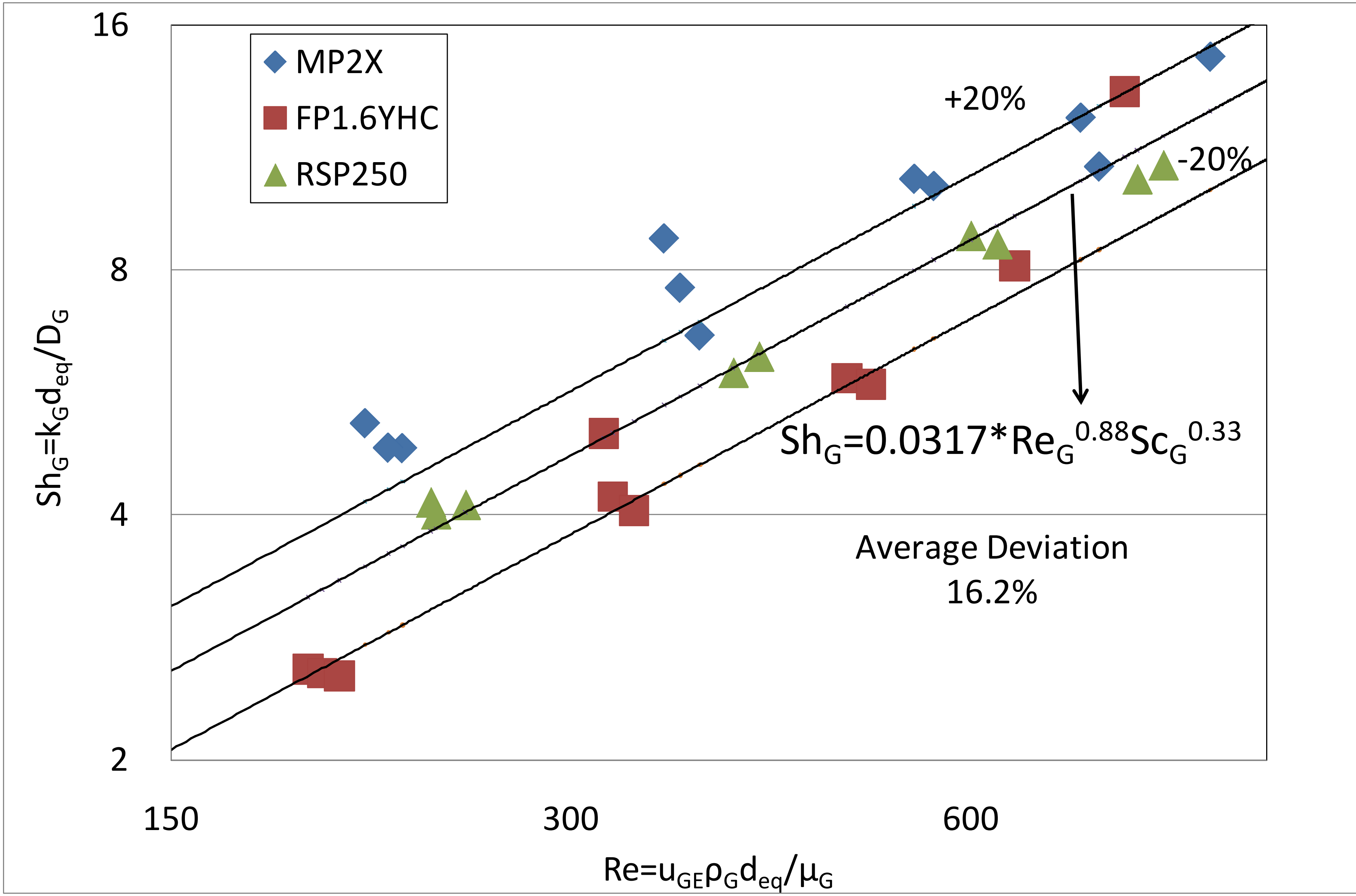
$$\frac{k_G S}{D_G} = 0.054\left(\frac{(u_{GE}+u_{LE})\rho_G S}{\mu_G}\right)^{0.8}\left(\frac{\mu_G}{D_G\rho_G}\right)^{0.33}$$

$$\frac{k_G}{a_P D_G} = 0.032\left(\frac{(u_{GE}+u_{LE})\rho_G}{a_P\mu_G}\right)^{0.88}\left(\frac{\mu_G}{\rho_G D_G}\right)^{0.33}$$

$$u_{GE} = \frac{u_{GS}}{\varepsilon(1-h_L)\sin\theta}$$

1. Rocha JA, Bravo JL, Fair, JR. "Distillation Columns Containing Structured Packings: A Comprehensive Model for Their Performance. 2. Mass-Transfer Model." Ind Eng Chem Res. 1996;35:1660–1667.

# $k_G$ model



16
8
4
2
150
300
600
MP2X
FP1.6YHC
RSP250
+20%
-20%
$Sh_G=0.0317*Re_G^{0.88}Sc_G^{0.33}$
Average Deviation
16.2%
$Sh_G=k_Gd_{eq}/D_G$
$Re=u_{GE}\rho_Gd_{eq}/\mu_G$

# Liquid film Mass Transfer Coefficient

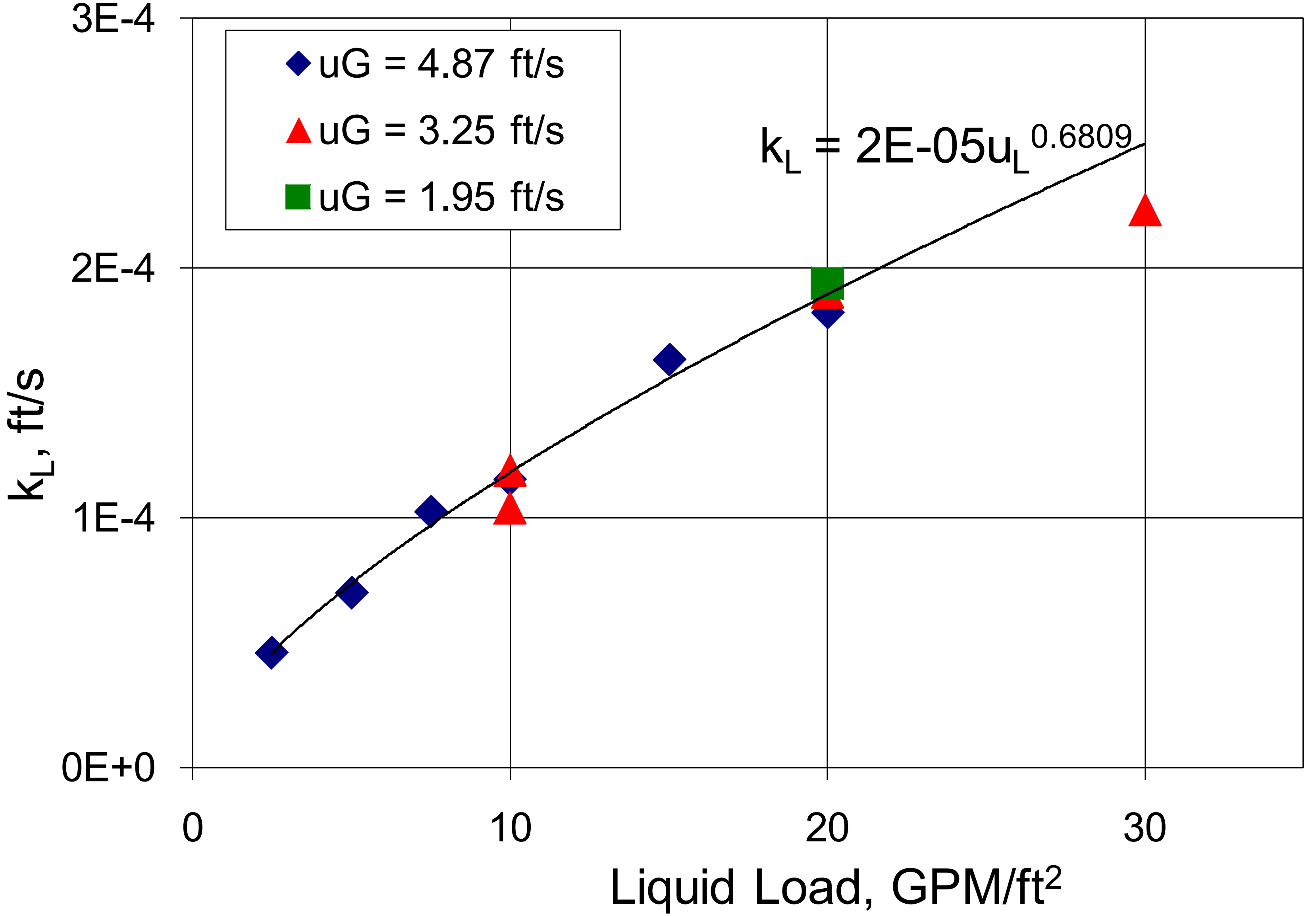
- Liquid film control (Air/Toluene/Water system)
- No chemical reactions
- Mass transfer resistance mainly in liquid film

stripping:

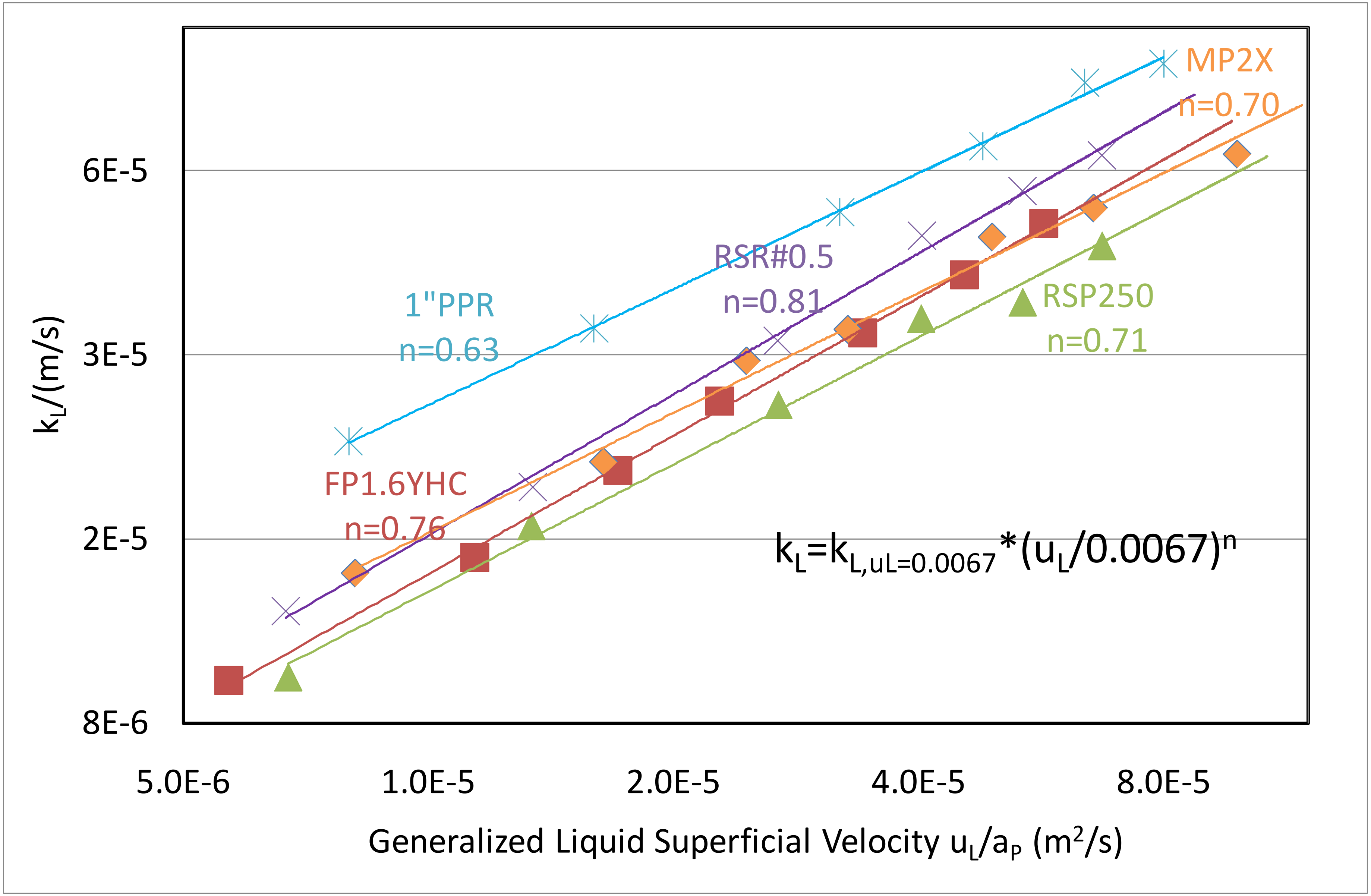
$$k_L a = \frac{u_L}{Z}\ln(c_{Lin} / c_{Lout})$$

- $$k_L = \frac{k_L a}{a_e}$$

# Liquid film mass transfer coefficient $k_L$ of MP2X



# $k_L$ summary



MP2X
n=0.70
RSR#0.5
n=0.81
1"PPR
n=0.63
RSP250
n=0.71
FP1.6YHC
n=0.76
$k_L = k_{L,uL=0.0067} * (u_L/0.0067)^n$
6E-5
3E-5
2E-5
8E-6
$k_L/(m/s)$
5.0E-6
1.0E-5
2.0E-5
4.0E-5
8.0E-5
Generalized Liquid Superficial Velocity $u_L/a_P$ ($m^2/s$)

# Brunazzi[2] dimensionless $k_L$ model (1997)

$$Sh_L = A\frac{Gz^B}{Ka^C}$$ A=409, B=0.5, C=0.09

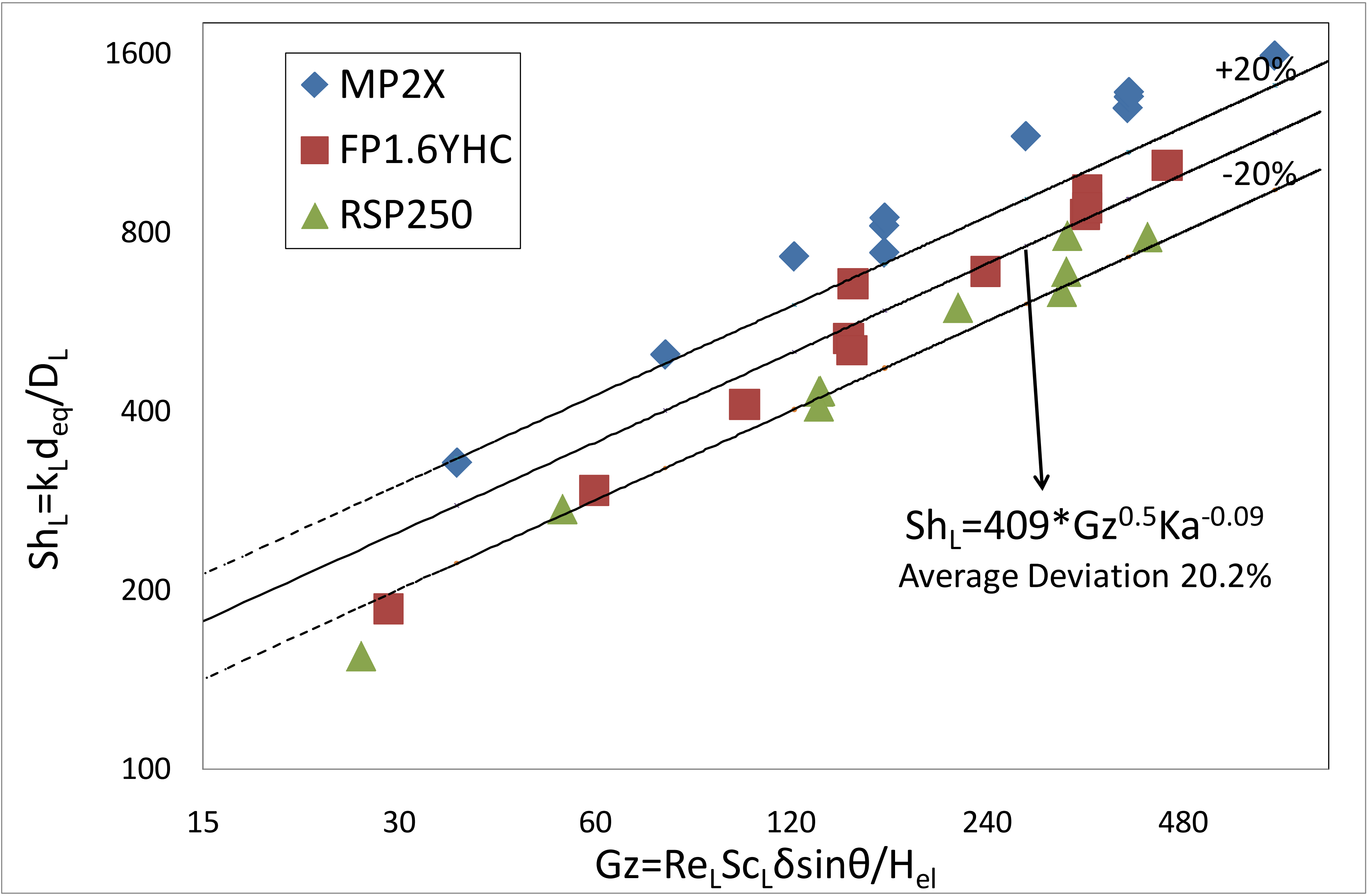
$$Gz = \mathrm{Re}_L\, Sc_L \frac{\delta \sin\theta}{H_{el}} \qquad \mathrm{Re}_L = \frac{\rho_L S U_{LE}}{\mu_L} \qquad Sc_L = \frac{\mu_L}{\rho_L D_L}$$

$$Ka = \frac{\sigma^3 \rho_L}{\mu_L{}^4 g} \qquad \delta = \left(\frac{3\mu_L}{\rho_L g \sin\theta}\frac{U_{LS}}{h_L \sin\theta}\right)^{0.5} \qquad u_{LE} = \frac{u_{LS}}{\varepsilon h_L \sin\theta}$$

- Consider the mixing of liquid phase occurs at junctions. Kapista number Ka
- Includes the flow path length factor, which is $H_{el}/\sin\theta$□
- Includes packing geometry factor S, liquid film thickness


- 2.Brunazzi E, Paglianti A. "Liquid-Film Mass Transfer Coefficient in a column Equipped with Structured Packings." Ind Eng Chem Res. 1997;36:3792-3799

# $k_L$ model


MP2X
FP1.6YHC
RSP250
+20%
-20%
1600
800
400
200
100
15
30
60
120
240
480
Sh_L=k_L d_eq/D_L
Gz=Re_L Sc_L δsinθ/H_el
Sh_L=409*Gz^0.5 Ka^-0.09
Average Deviation 20.2%

# Conclusions

- $a_e$ is a function of L, $\sim u_L^{0.155}$, not a function of G ,

Tsai's area model: $$\frac{a_e}{a_p} = 1.42[(\frac{\rho_L}{\sigma})g^{1/3}(\frac{Q}{A}*\frac{1}{a_p})^{4/3}]^{0.116}$$

- $k_G \sim u_G^{0.88}$, not a function of $u_L$

Modified RBF $k_G$ model: $$Sh_G = 0.0317*\mathrm{Re}_G^{\ 0.88} Sc_G^{\ 0.33}$$

- $k_L \sim u_L^{0.74}$, not a function of $u_G$

Modified RBF $k_L$ model: $$Sh_L = 409*Gz^{0.5}Ka^{-0.09}$$

# Thank You

Question?

Chao Wang

wangchao@che.utexas.edu