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TALLINN UNIVERSITY OF TECHNOLOGY

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Two-Phase Boundary Layer

by

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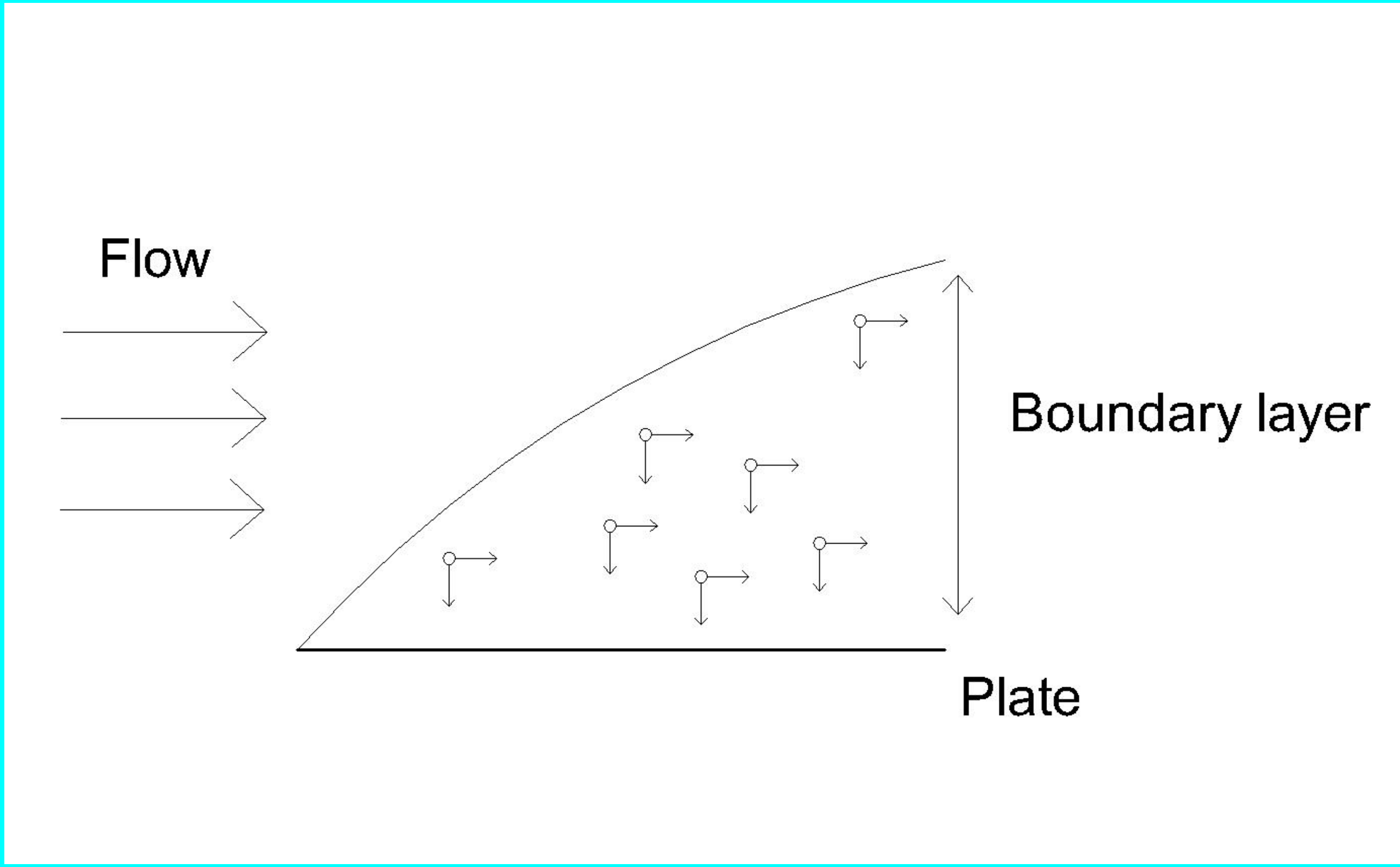
Schematic of flow domain



Two-phase flow conditions

- horizontal flow

horizontal flat plate: 0.5 m length, 0.1 m width, 0.002 m thickness

flat-plate boundary layer

flow velocity U_∞=5 ms^{-1}

12, 23, 32-μm corundum particles (ρ_p=3950 kgm^{-3})

flow mass loading æ=0.07 and 0.14 kg dust/kg air

Assumptions:

a) Boundary Layer Concept

b) Two-fluid/coexisted flows

Force factors

i). Viscous drag force

ii). Gravitation

iii) Saffman force

iv) Magnus force

Two-Phase Laminar Boundary Layer Eqs.

$$xu\frac{\partial u}{\partial x}+\left(V-\frac{u\eta}{2}\right)\frac{\partial u}{\partial \eta}=\frac{\partial^2 u}{\partial \eta^2}-x\alpha\left[C_D'\frac{(u-u_s)}{\tau}+C_M(v-v_s)\left(0.5\sqrt{\frac{Re_\infty}{x}}\frac{\partial u}{\partial \eta}-\omega_s\right)\right] \quad (1)$$

$$V\equiv v\sqrt{x\,Re_\infty}=-u\int_0^{\Delta\infty}\left[\frac{\partial}{\partial \eta}\left(\frac{\partial u}{\partial \eta}\right)-xC_D'\alpha\frac{(u-u_s)}{\tau}\right]\frac{d\eta}{u^2} \quad (2)$$

$$xu_s\frac{\partial u_s}{\partial x}+\left[V_s-\left(\frac{\eta u_s}{2}+\frac{D_s}{\nu}\frac{\partial \ln\alpha}{\partial \eta}\right)\right]\frac{\partial u_s}{\partial \eta}=\frac{1}{\alpha}\frac{\partial}{\partial \eta}\left(\alpha\frac{\nu_s}{\nu}\frac{\partial u_s}{\partial \eta}\right)+x\left[C_D'\frac{(u-u_s)}{\tau}+\right.$$

$$\left.C_M(v-v_s)\left(0.5\sqrt{\frac{Re_\infty}{x}}\frac{\partial u}{\partial \eta}-\omega_s\right)\right] \quad (3)$$

$$xu_s \frac{\partial v_s}{\partial x} + \left[V_s - \left(\frac{\eta u_s}{2} + \frac{D_s}{\nu} \frac{\partial \ln \alpha}{\partial \eta} \right) \right] \frac{\partial v_s}{\partial \eta} = \frac{1}{\alpha} \frac{\partial}{\partial \eta} \left(\alpha \frac{\nu_s}{\nu} \frac{\partial v_s}{\partial \eta} \right) + x \left[C'_D \frac{(v - v_s)}{\tau} - \right. \tag{4}$$

$$\left. + C_F (u - u_s) \sqrt{\frac{Re_\infty}{x} \frac{\partial u}{\partial \eta}} - C_M (u - u_s) \left(0.5 \sqrt{\frac{Re_\infty}{x} \frac{\partial u}{\partial \eta}} - \omega_s \right) - g \left(1 - \frac{\rho}{\rho_p} \right) \right]$$

$$xu_s \frac{\partial \omega_s}{\partial x} + \left[V_s - \left(\frac{\eta u_s}{2} + \frac{D_s}{\nu} \frac{\partial \ln \alpha}{\partial \eta} \right) \right] \frac{\partial \omega_s}{\partial \eta} = \frac{1}{\alpha} \frac{\partial}{\partial \eta} \left(\alpha \frac{\nu_s}{\nu} \frac{\partial \omega_s}{\partial \eta} \right) + xC'_\omega \frac{\left(0.5 \sqrt{\frac{Re_\infty}{x} \frac{\partial u}{\partial \eta}} - \omega_s \right)}{\tau} \tag{5}$$

Boundary Conditions

$$\eta = 0: \quad u = v = v_s = 0, \quad \gamma\sqrt{\frac{Re_\infty}{x}}\frac{\partial u_s}{\partial \eta} = -u_s, \quad \gamma\sqrt{\frac{Re_\infty}{x}}\frac{\partial \omega_s}{\partial \eta} = \omega_s, \quad \frac{\partial \alpha}{\partial \eta} = 0, \tag{6}$$

$$\gamma = \delta\left(\sqrt[3]{\frac{\pi\rho}{6\rho_p\alpha}} - 1\right)$$ interparticle distance

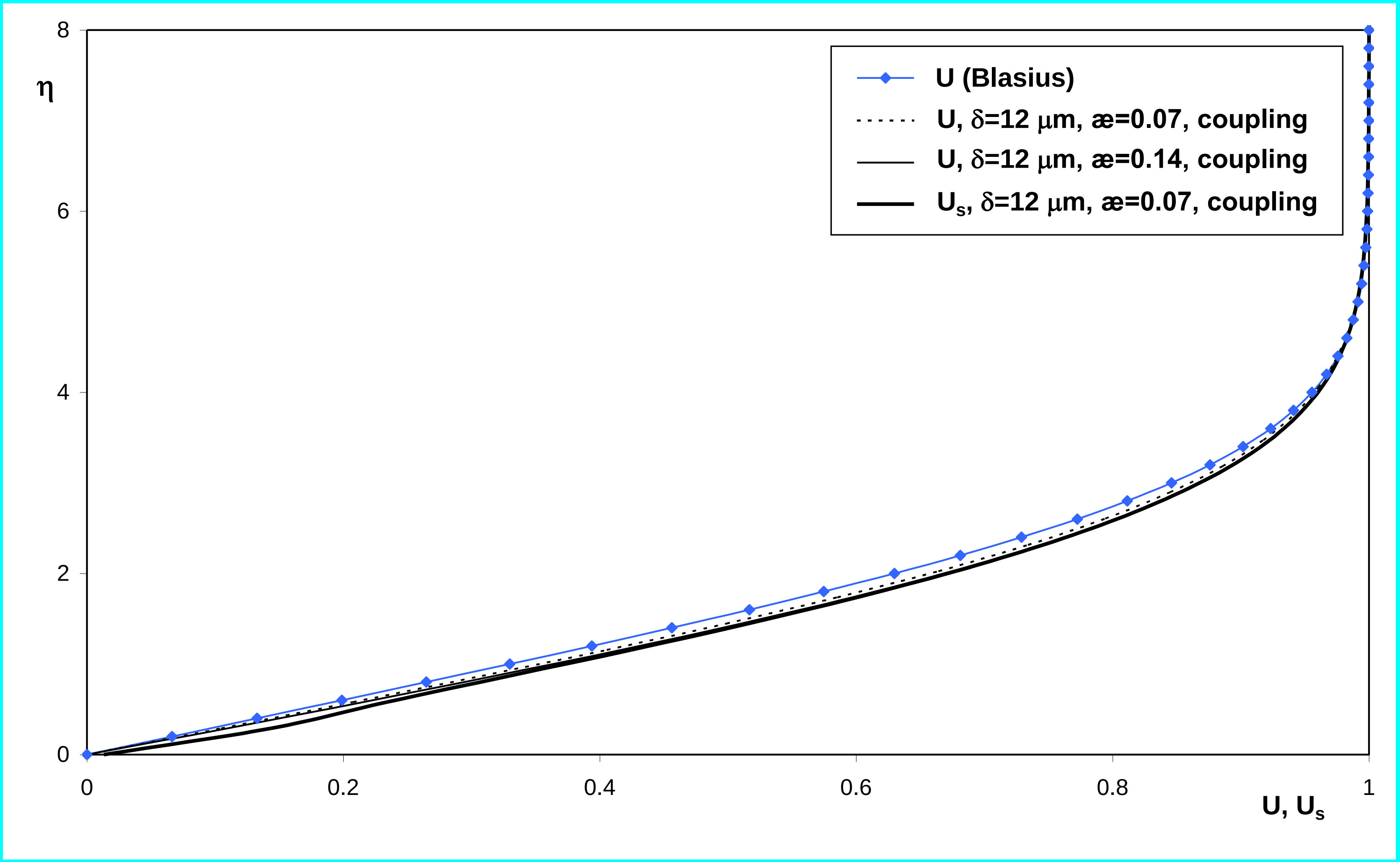
$$\eta = \Delta_\infty\sqrt{\frac{Re_\infty}{x}}: \quad u = u_s = \alpha = 1, \quad \frac{\partial v}{\partial \eta} = \frac{\partial v_s}{\partial \eta} = \frac{\partial \omega_s}{\partial \eta} = 0, \tag{7}$$

$$x = 0: \quad u = u_s = \alpha = 1, \quad v = v_s = \omega_s = 0, \tag{8}$$

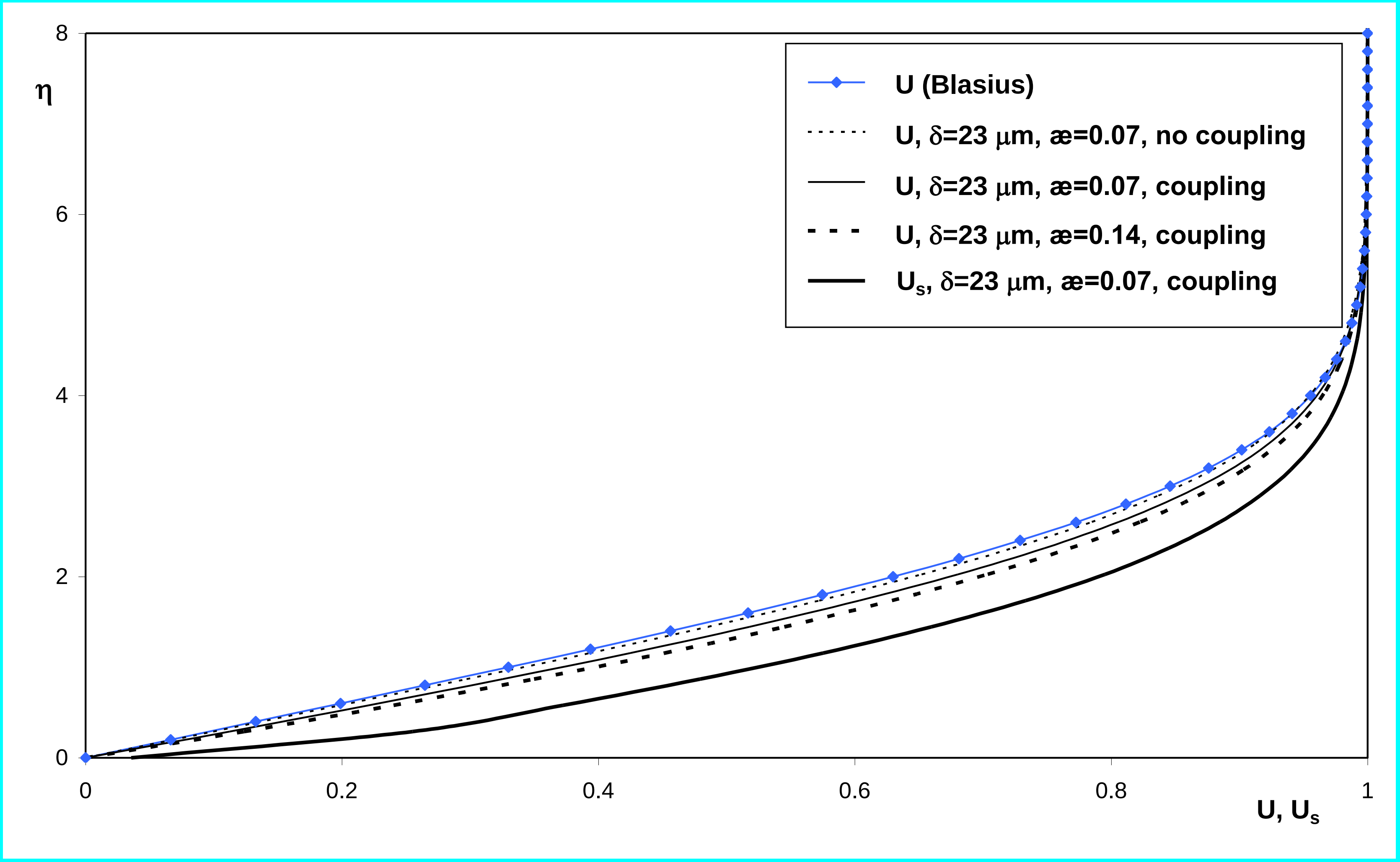
$$x = 1: \quad \frac{\partial u}{\partial x} = \frac{\partial v}{\partial x} = \frac{\partial u_s}{\partial x} = \frac{\partial v_s}{\partial x} = \frac{\partial \omega_s}{\partial x} = \frac{\partial \alpha}{\partial x} = 0 \tag{9}$$

Results

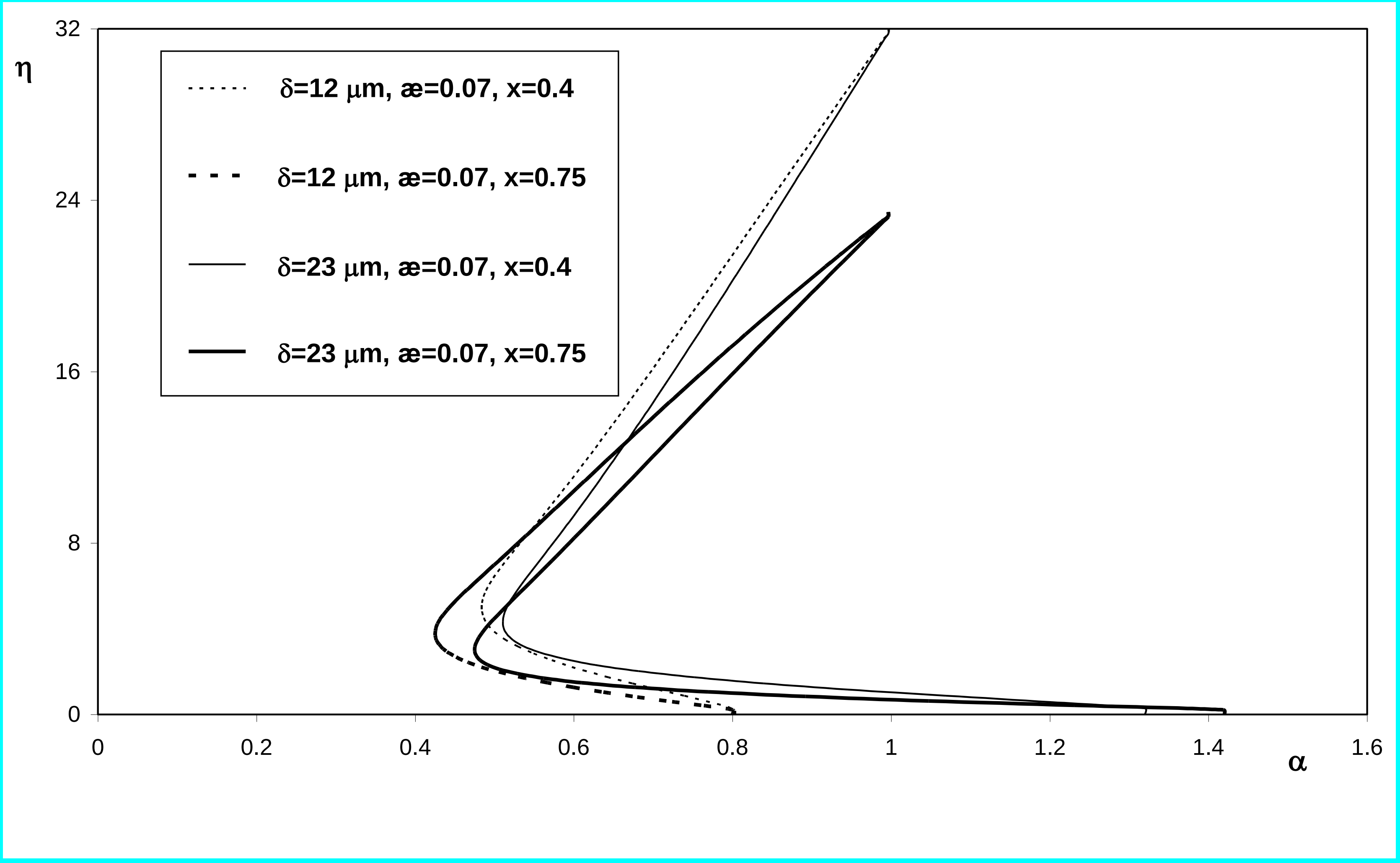
Profiles of non-dimensional axial velocities of gas and solid phases (self-similar coordinates) across the boundary layer



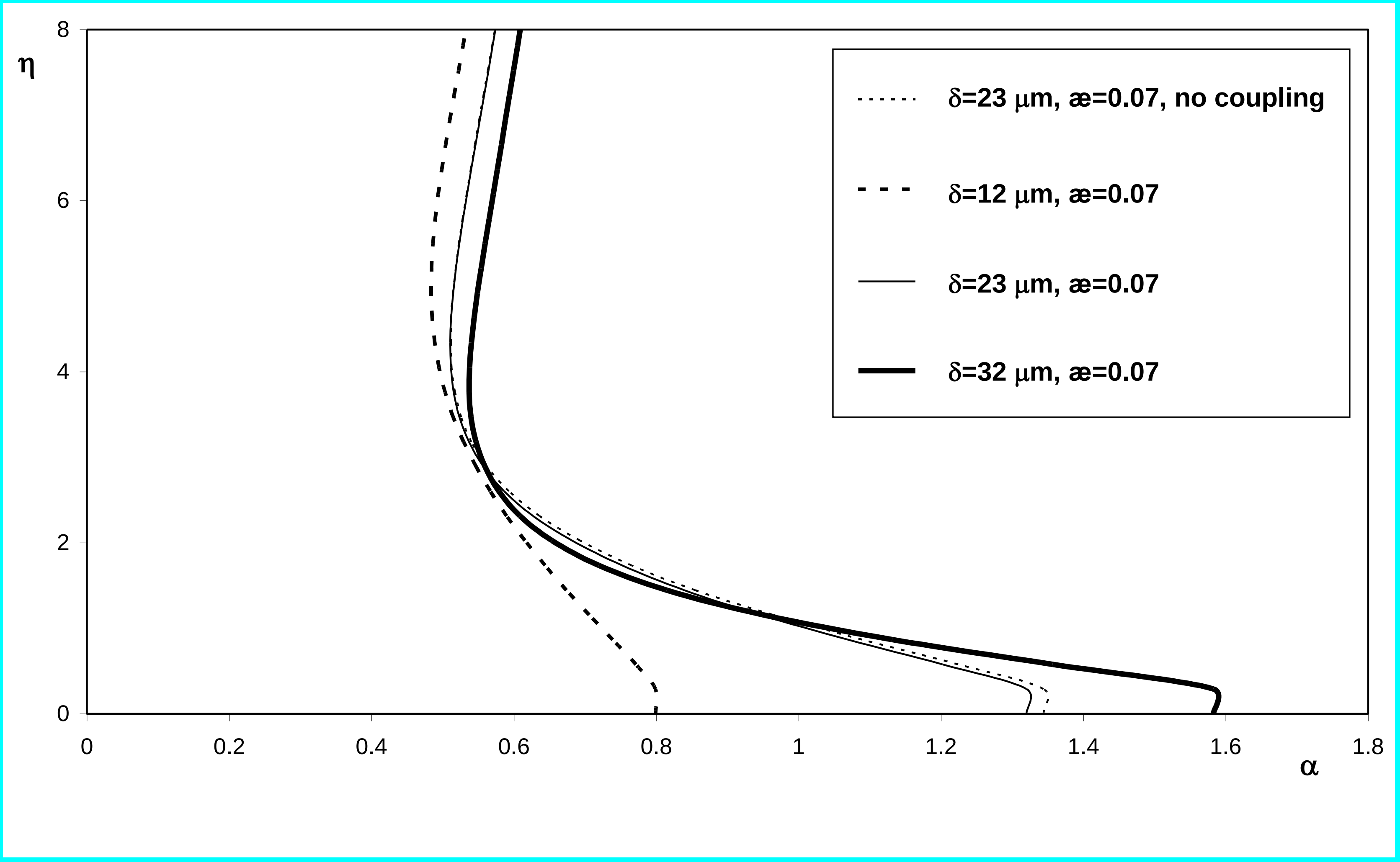
Profiles of non-dimensional axial velocities of gas and solid phases across the boundary layer



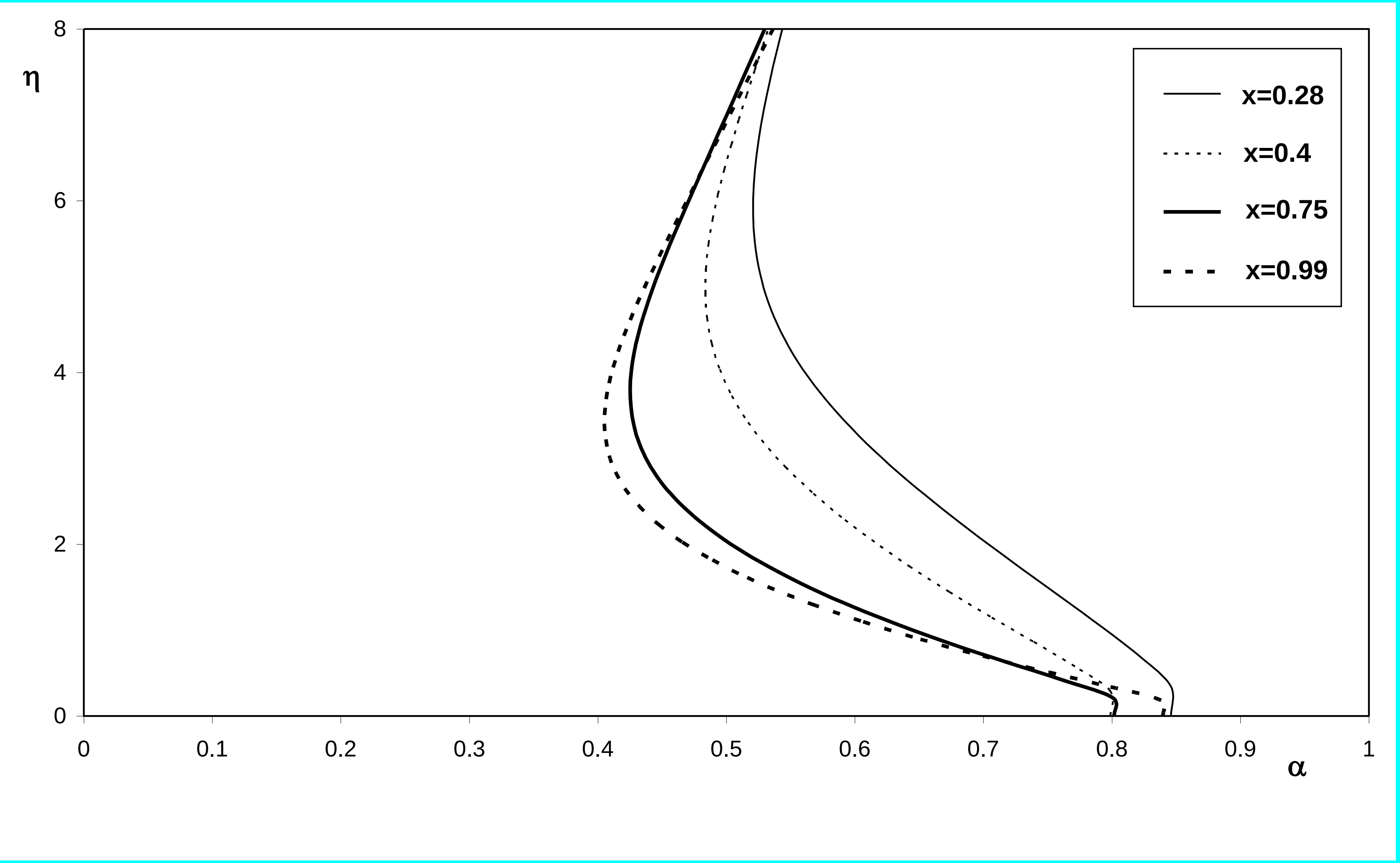
Profiles of particle mass concentration across the boundary layer in two locations *x*



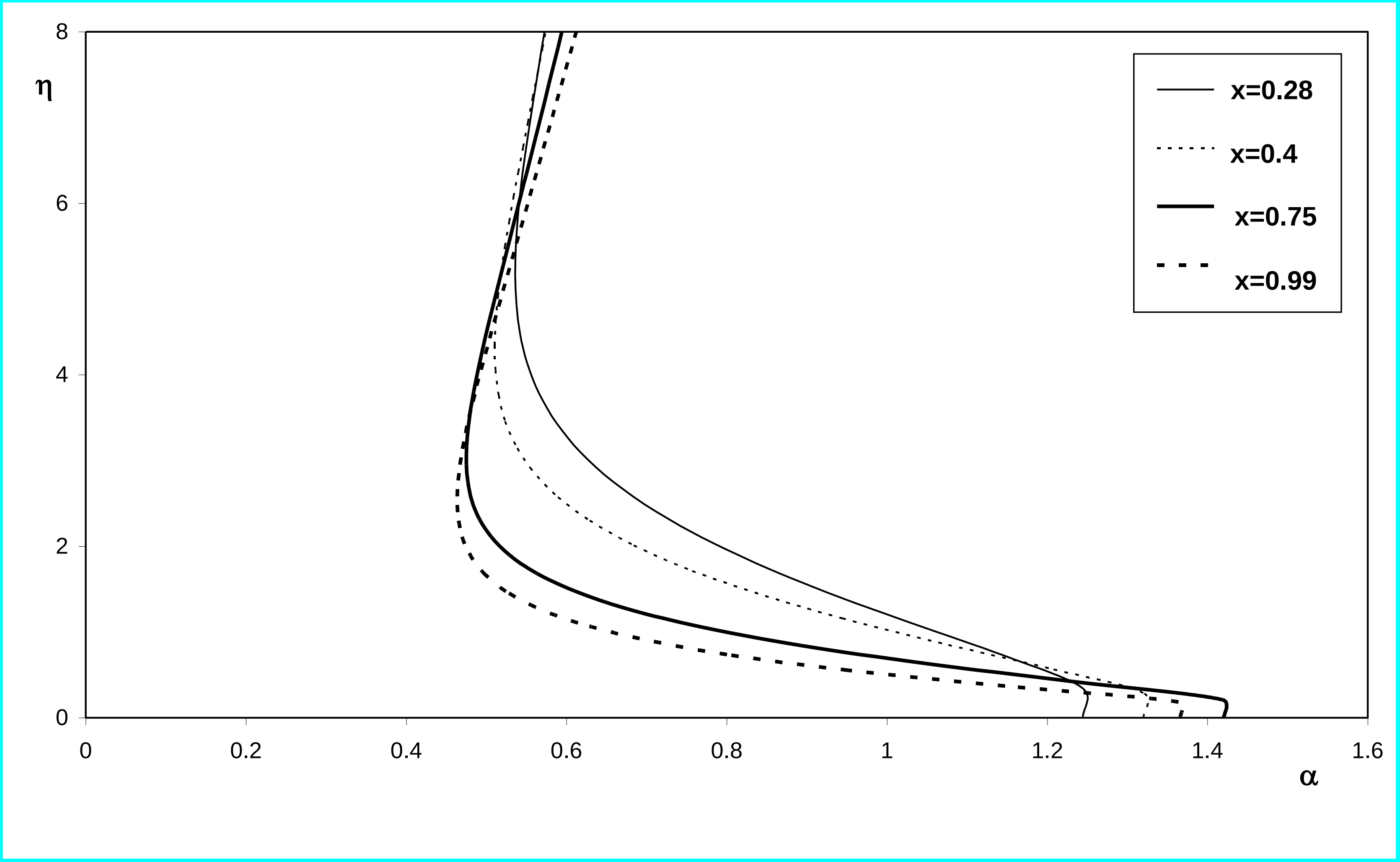
Profiles of particle mass concentration across the boundary layer



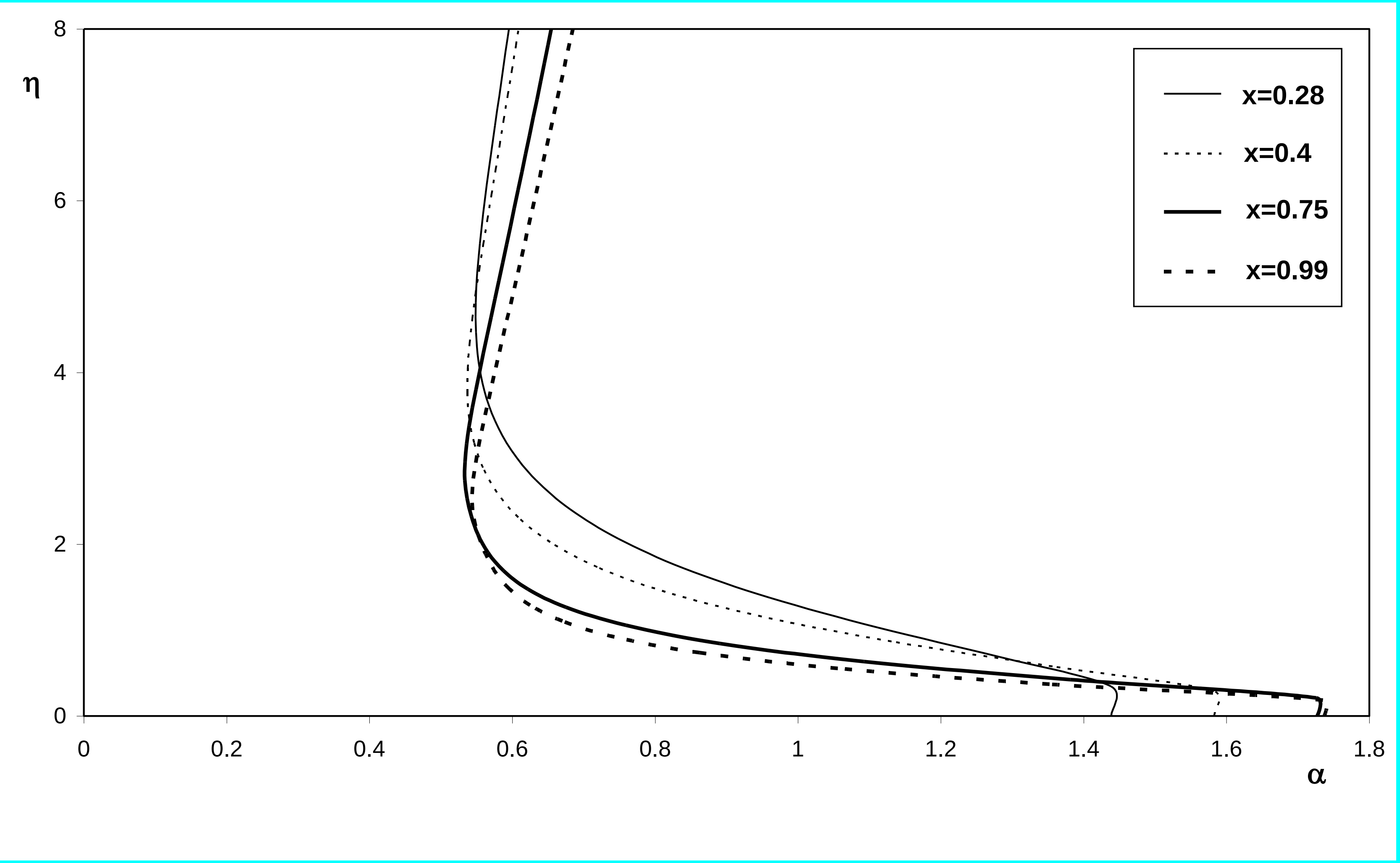
Profiles of particle mass concentration across the boundary layer; δ=12 μm, æ=0.07



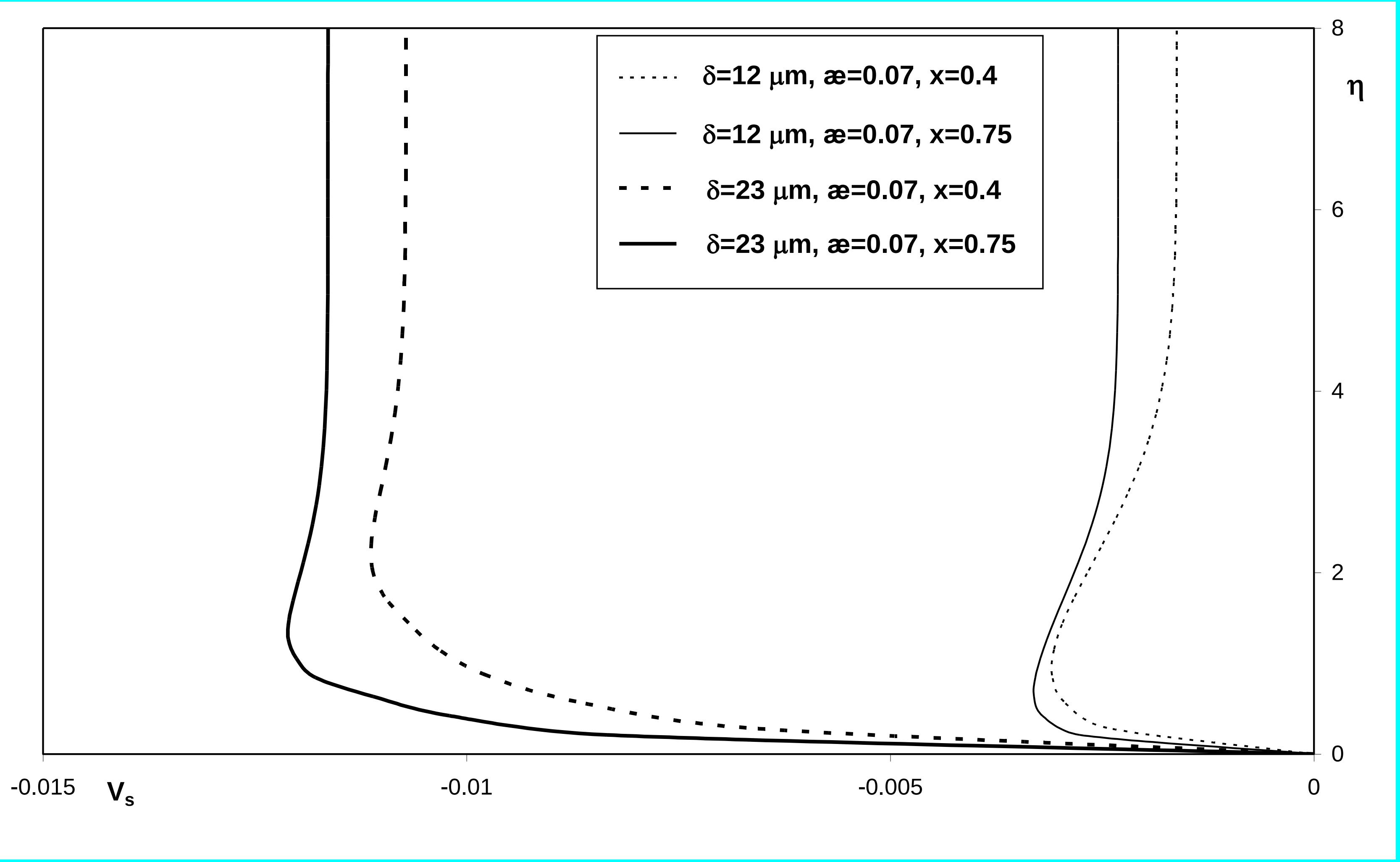
Profiles of particle mass concentration across the boundary layer; δ=23 μm, æ=0.07



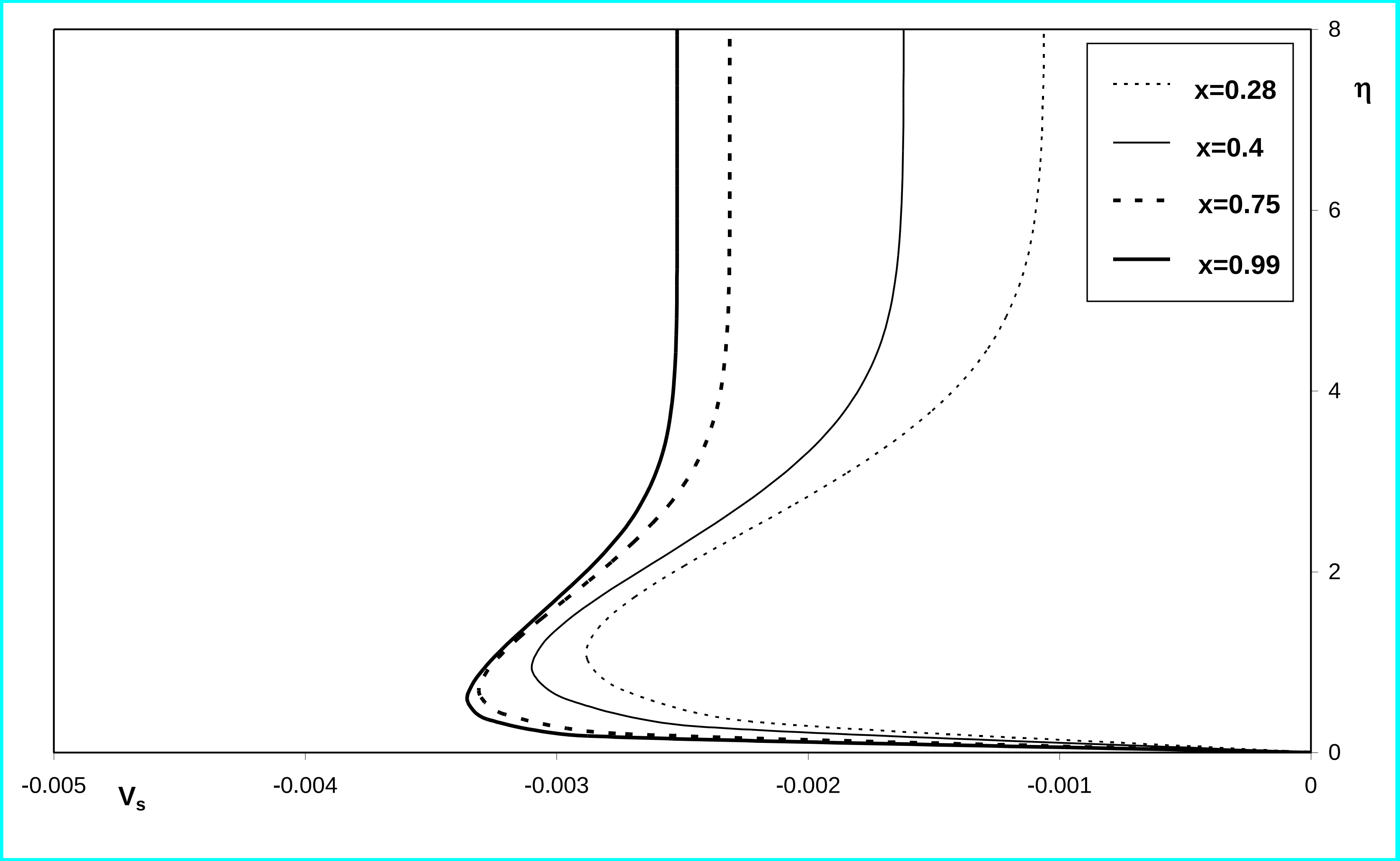
Profiles of particle mass concentration across the boundary layer; δ=32 μm, æ=0.07



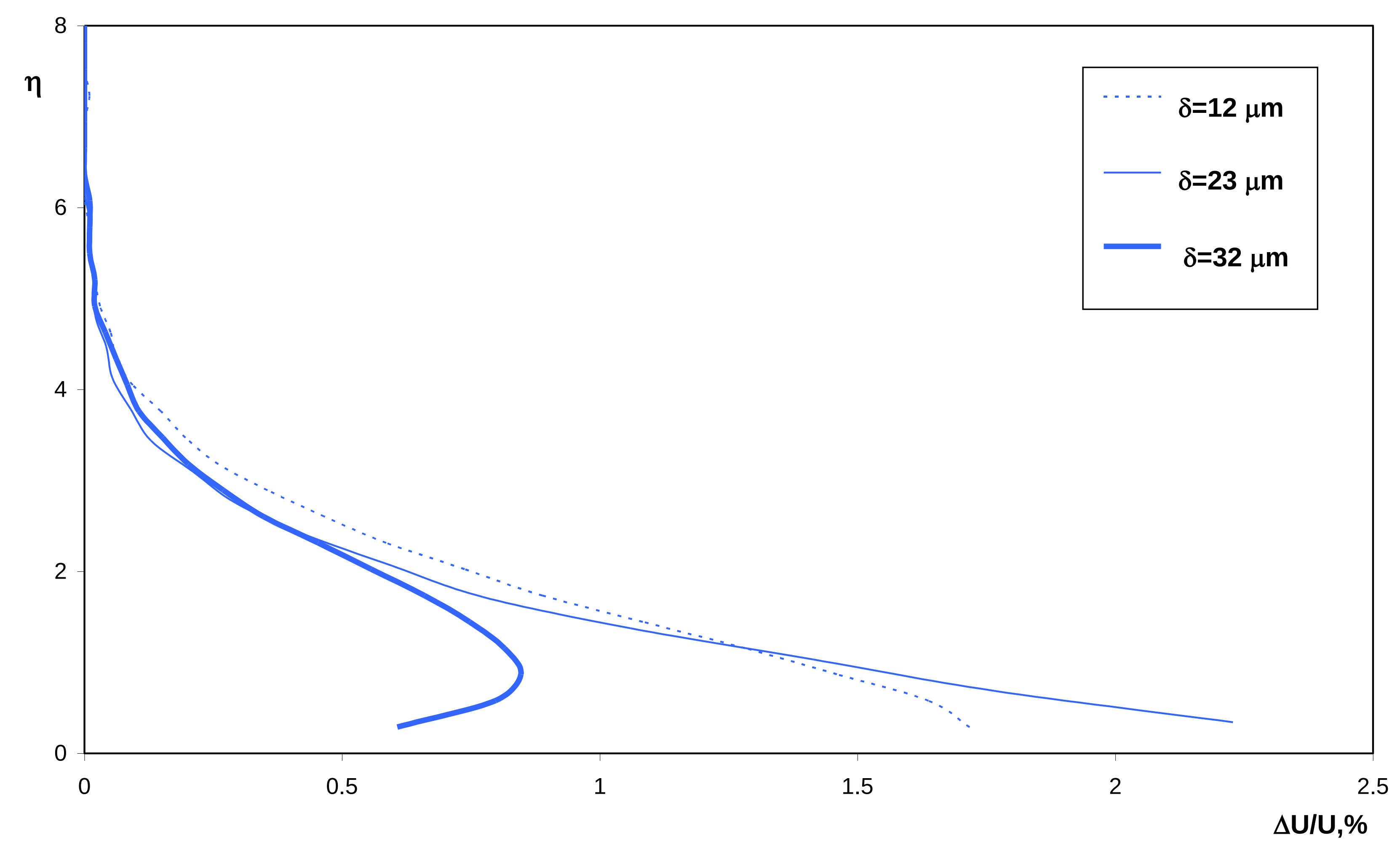
Profiles of transversal velocity of particles across the boundary layer in two locations *x/L=0.4 & x/L=0.75*



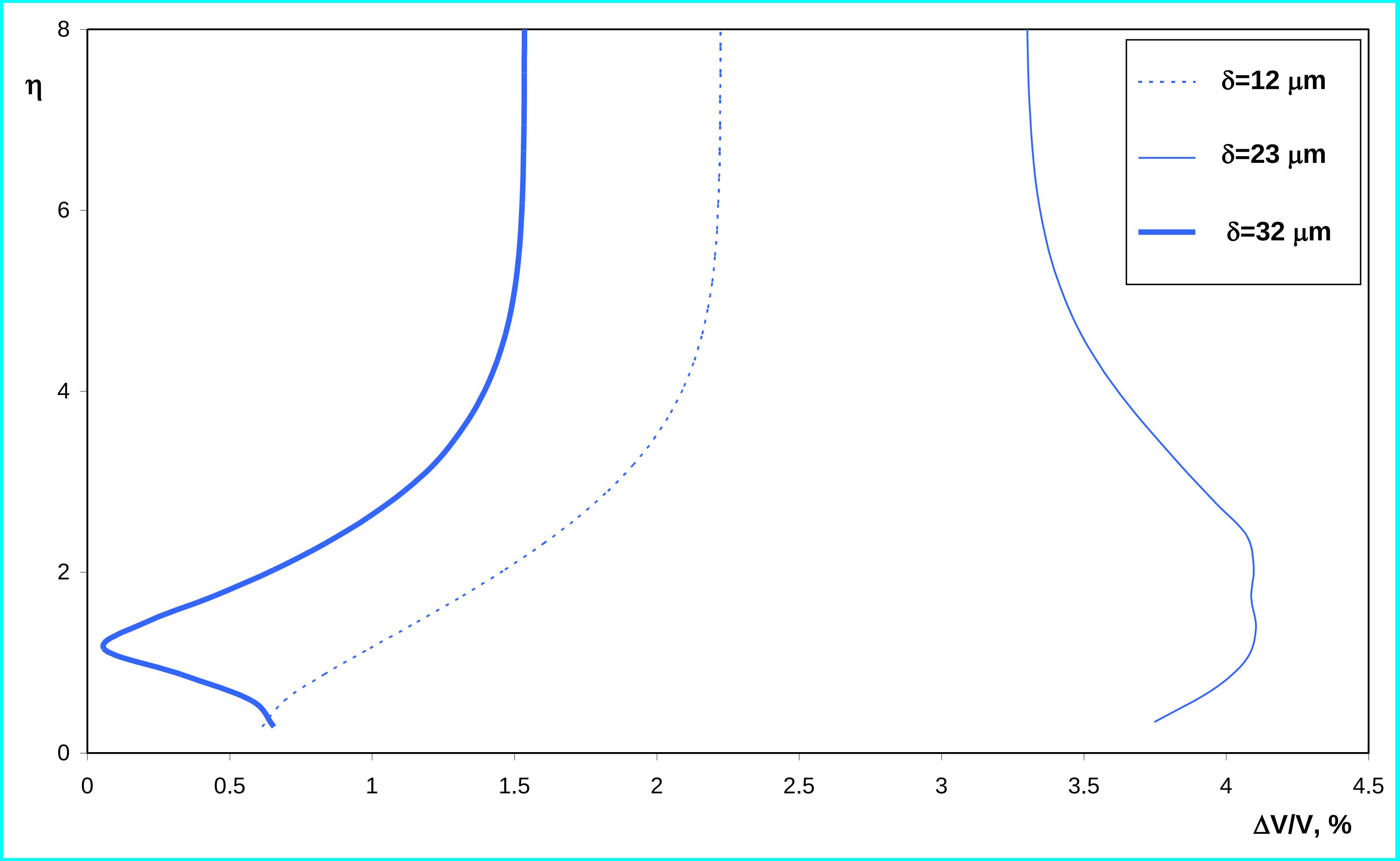
Profiles of transversal velocity of particles across the boundary layer; δ=12 μm, æ=0.07



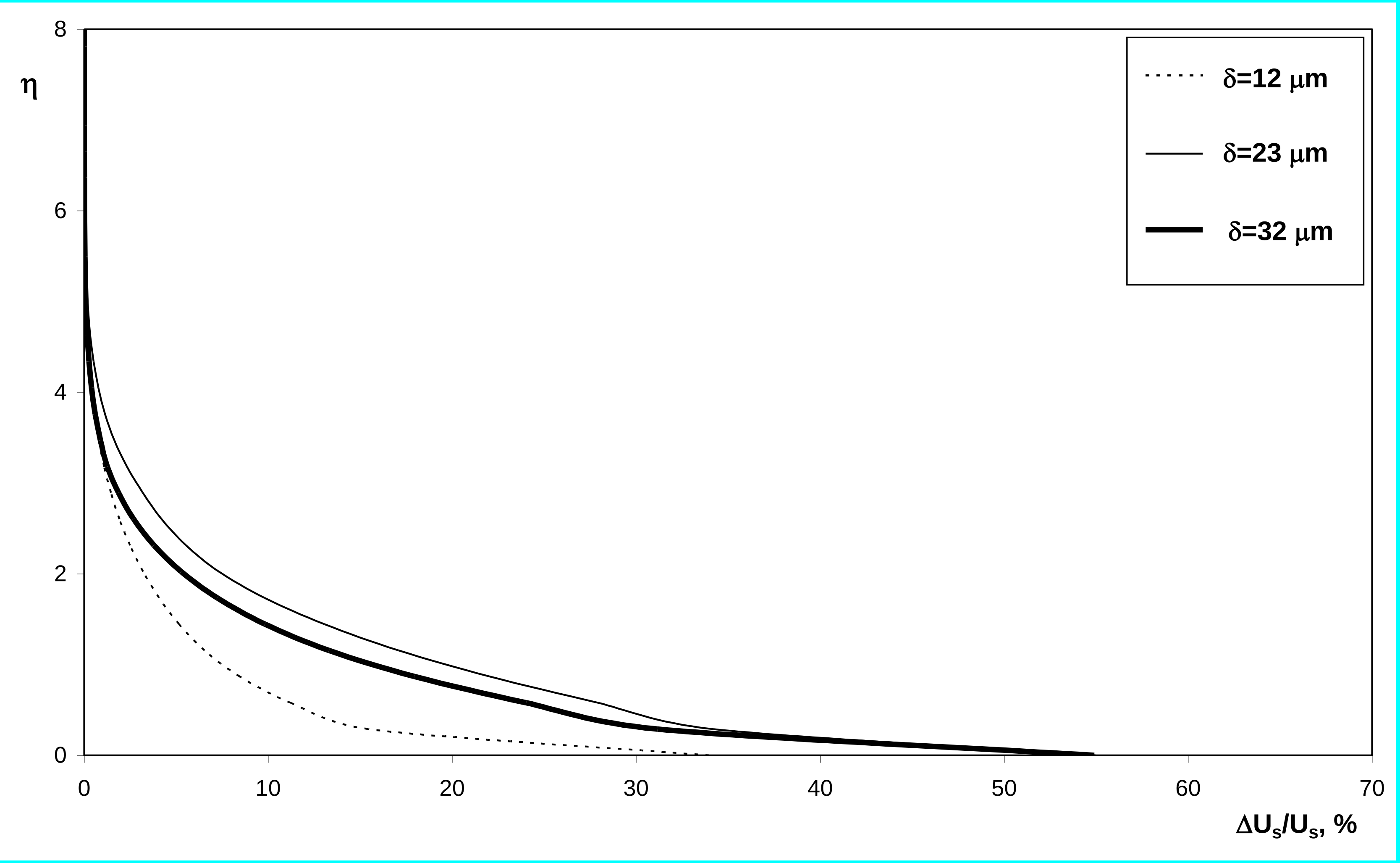
Effect of the particles shape factor on axial velocity of gas



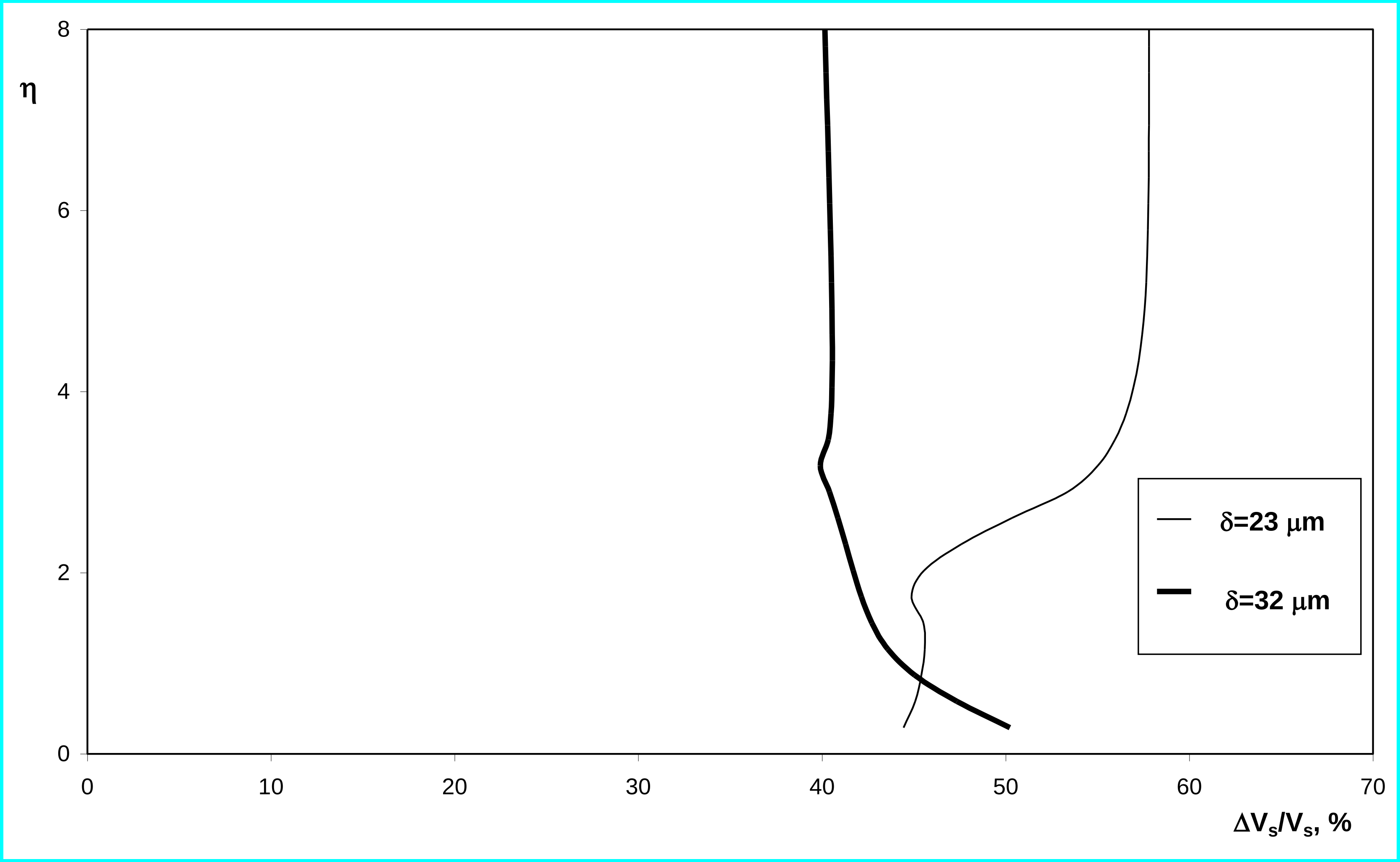
Effect of the particles shape factor on transversal velocity of gas



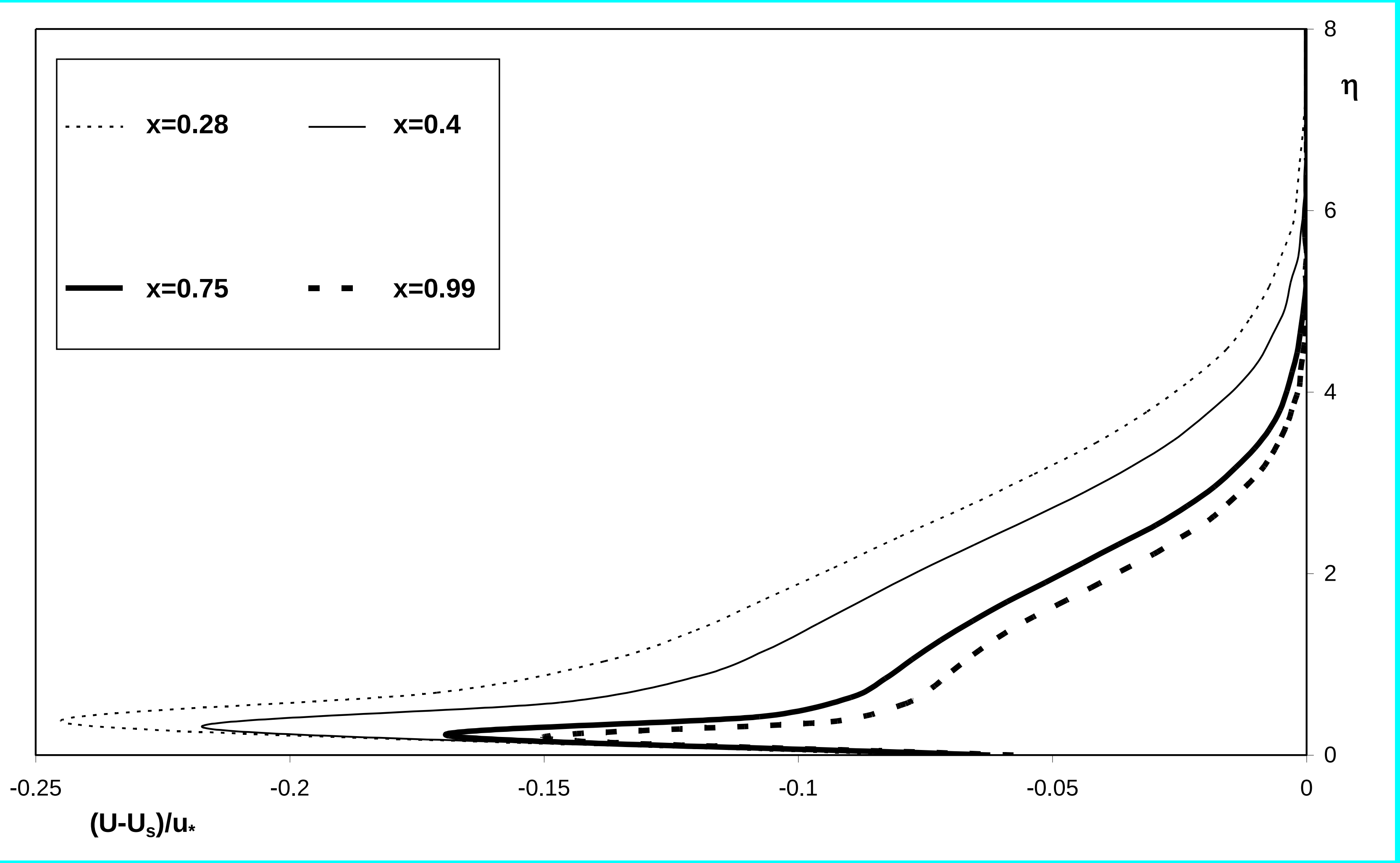
Effect of the particles shape factor on axial velocity of particles



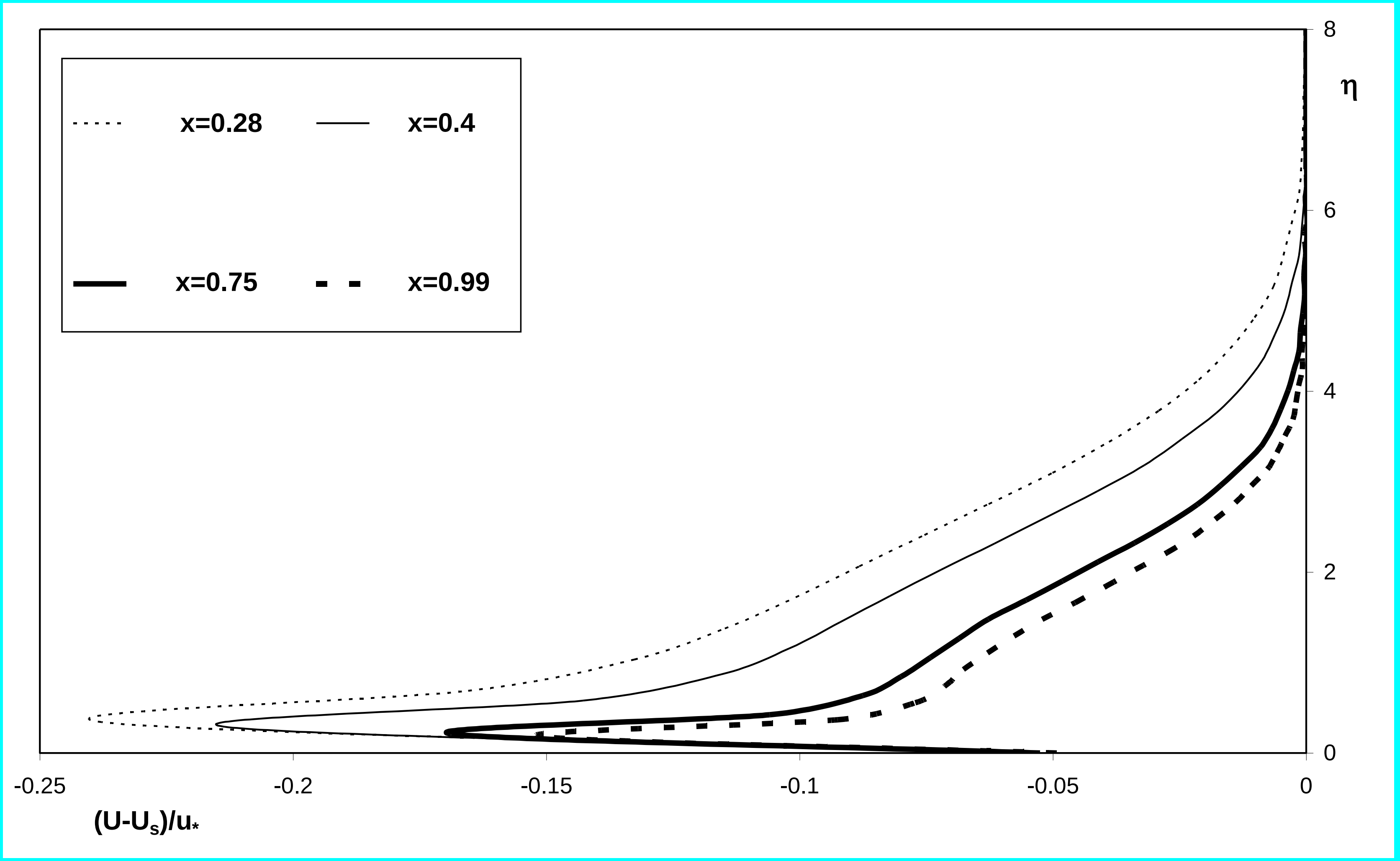
Effect of the particles shape factor on transversal velocity of particles



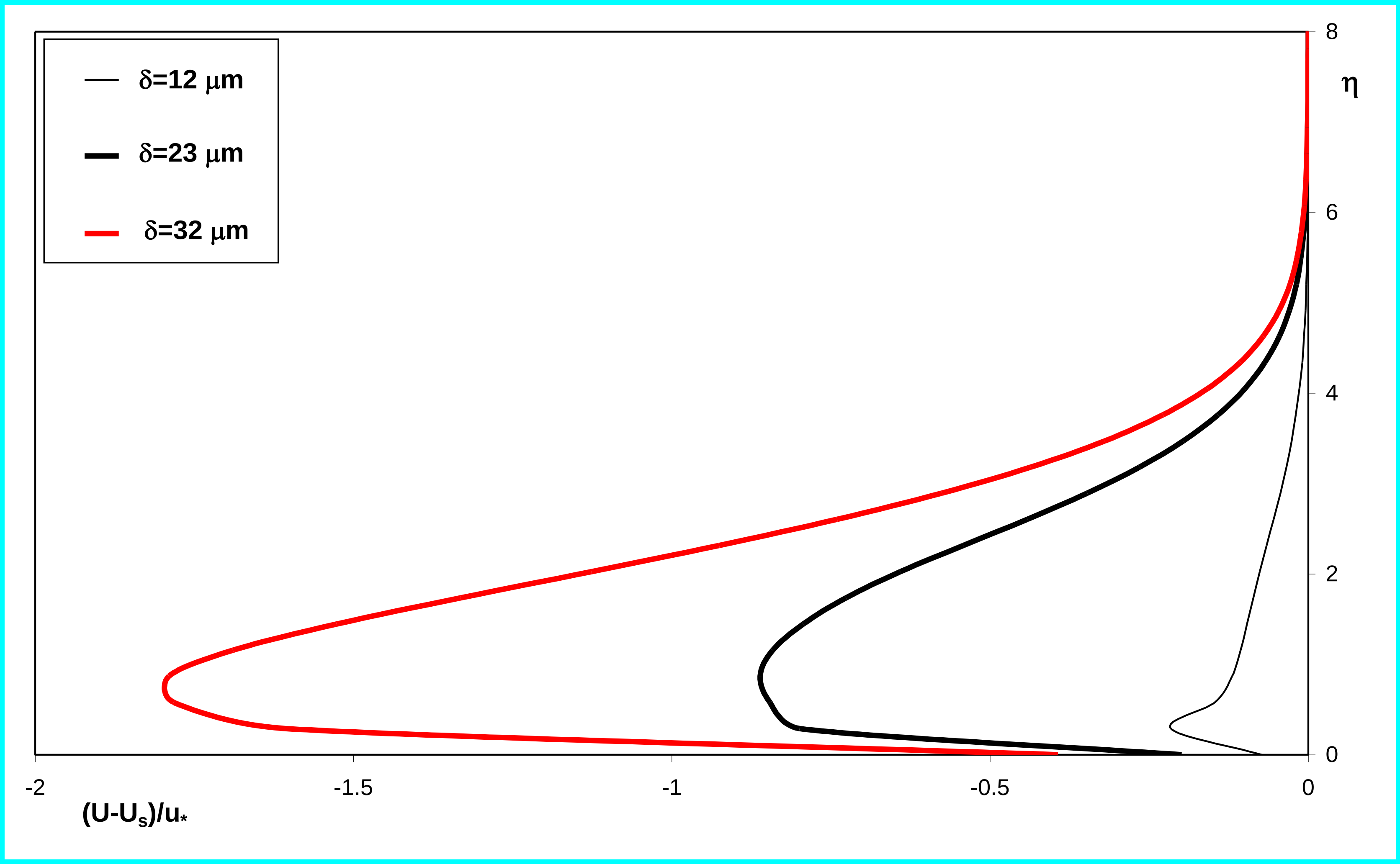
Profiles of axial slip velocity normalized to friction velocity; δ=12 μm, æ=0.07



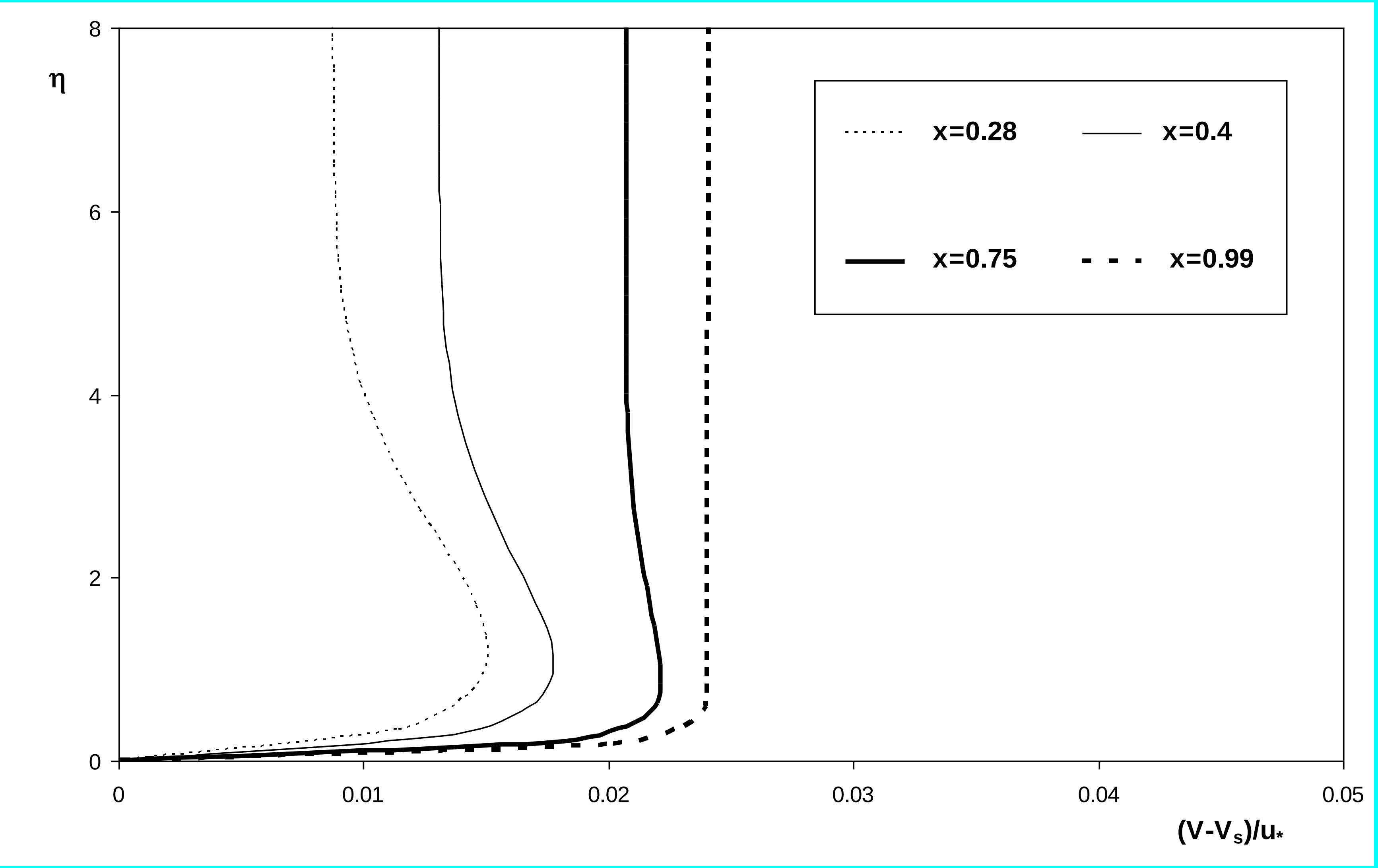
Profiles of axial slip velocity normalized to friction velocity; δ=12 μm, æ=0.14



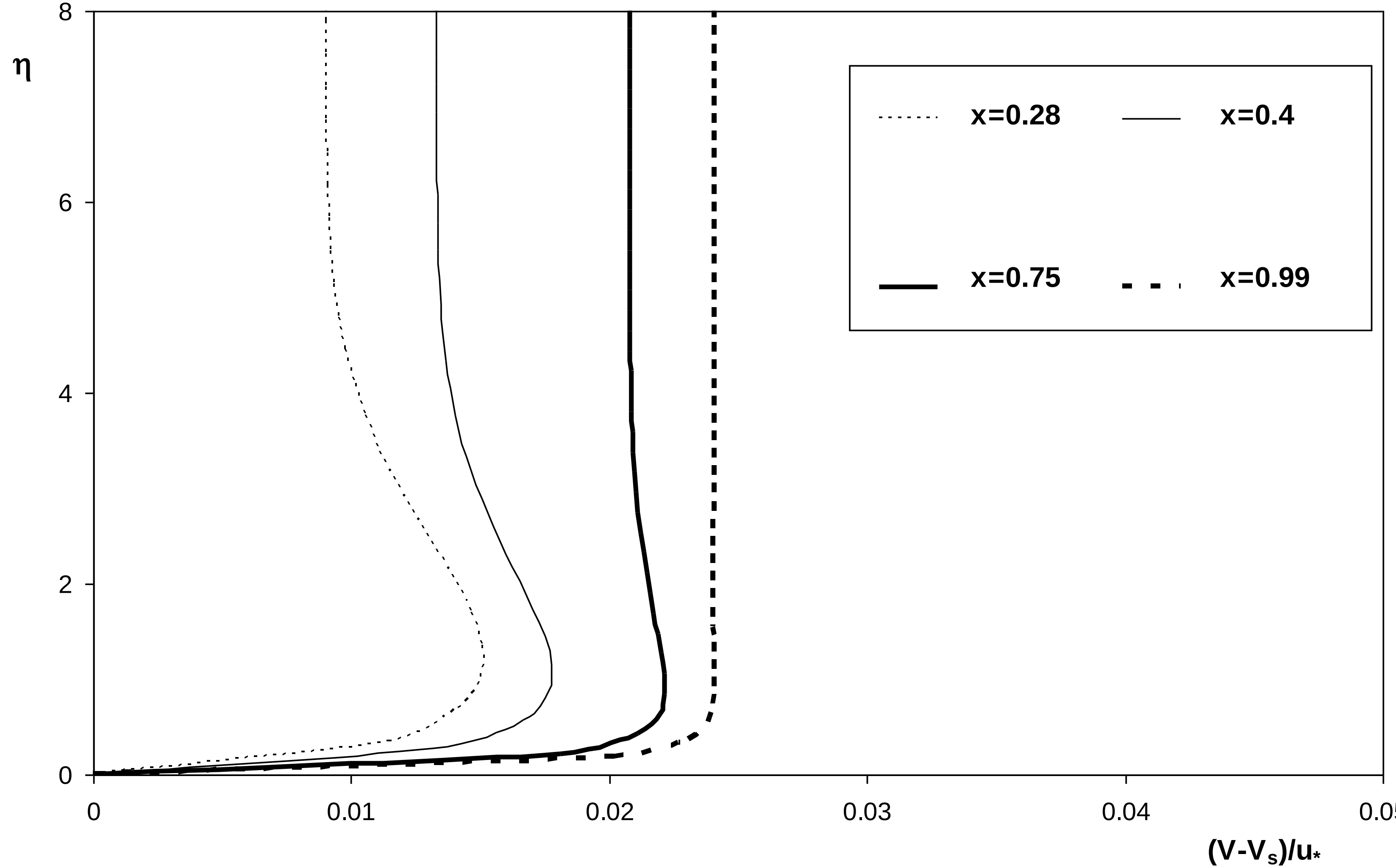
Profiles of axial slip velocity normalized to friction velocity; æ=0.07, x=0.4



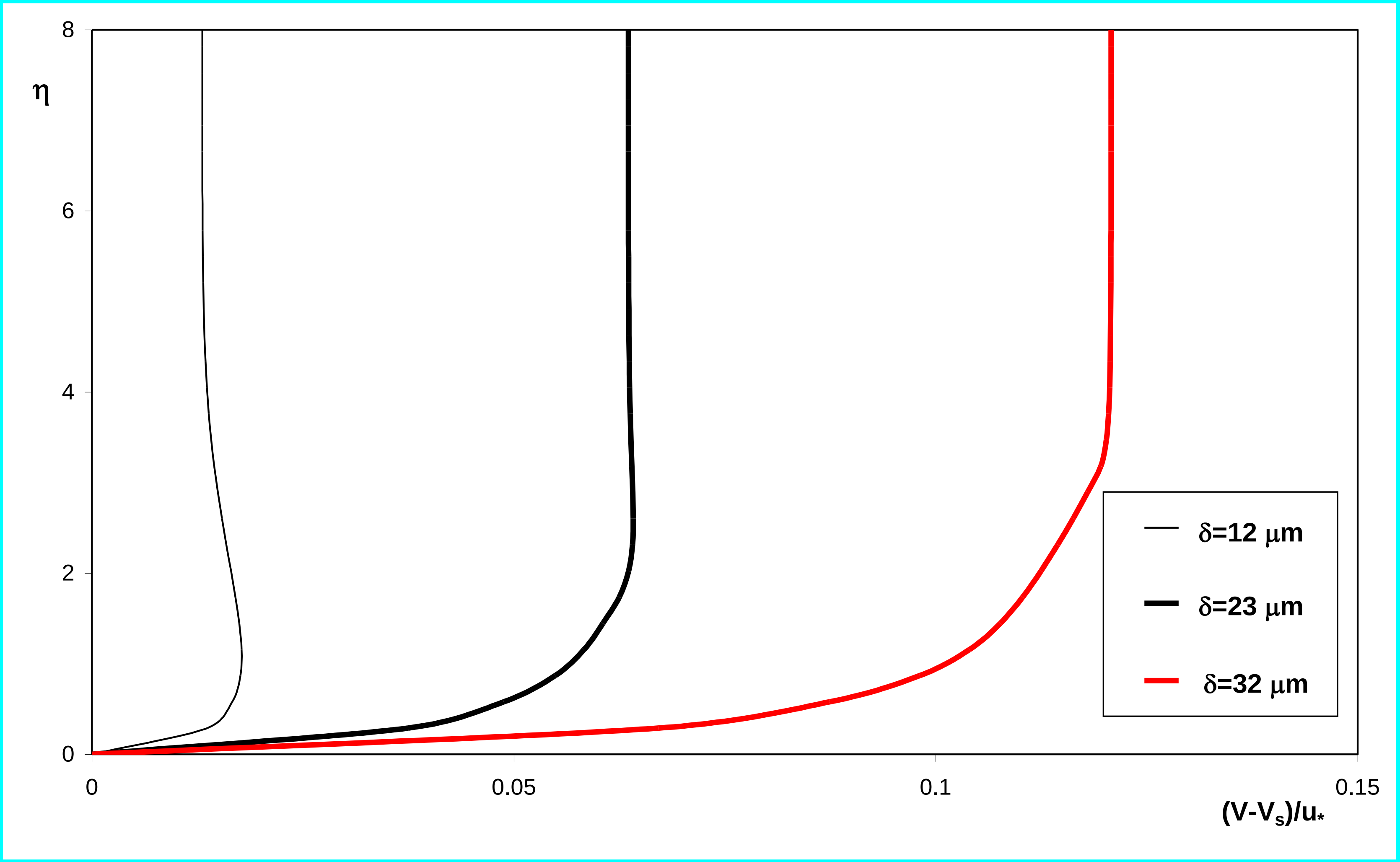
Profiles of transversal slip velocity normalized to friction velocity; δ=12 μm, æ=0.07



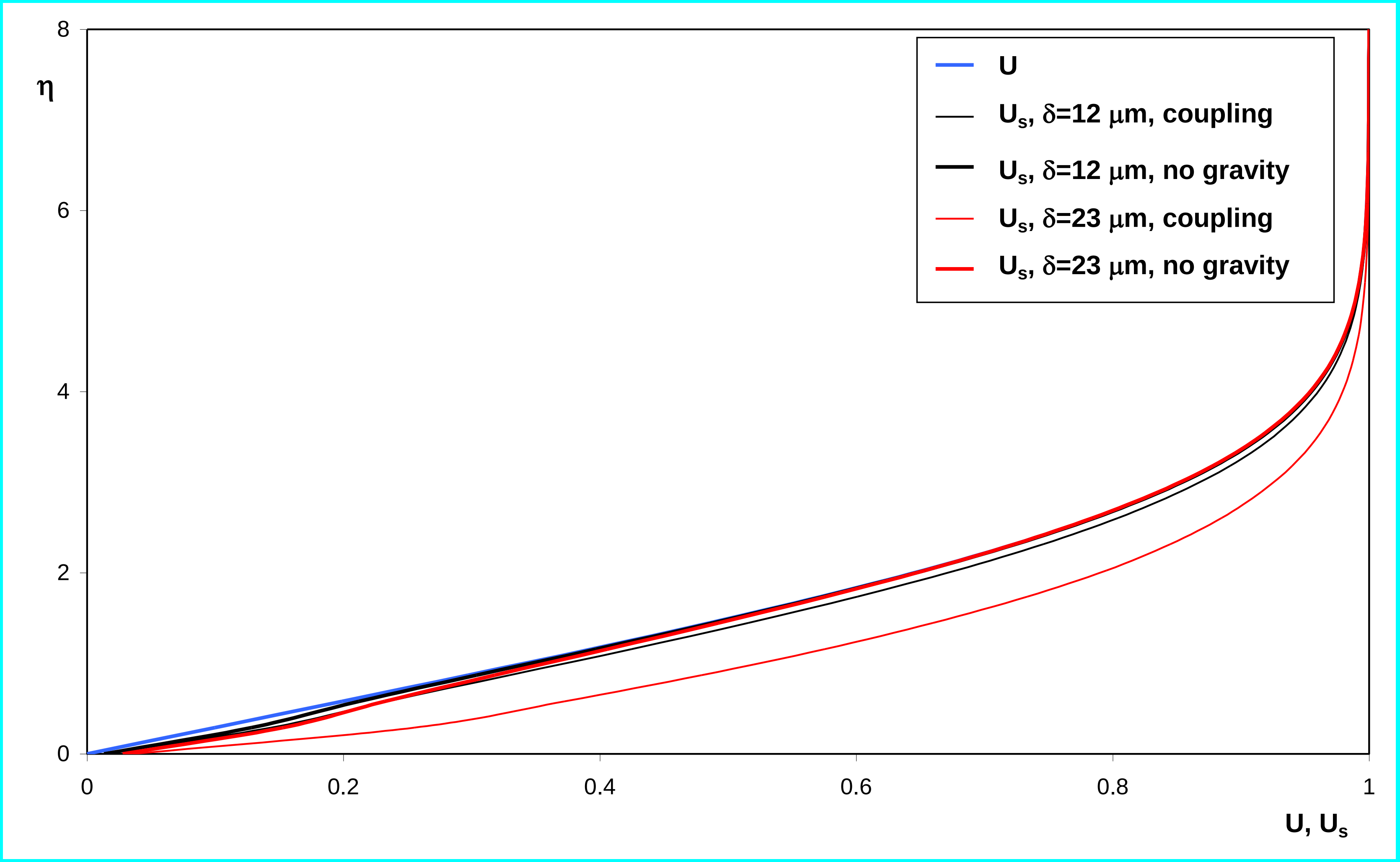
Profiles of transversal slip velocity normalized to friction velocity; δ=12 μm, æ=0.14



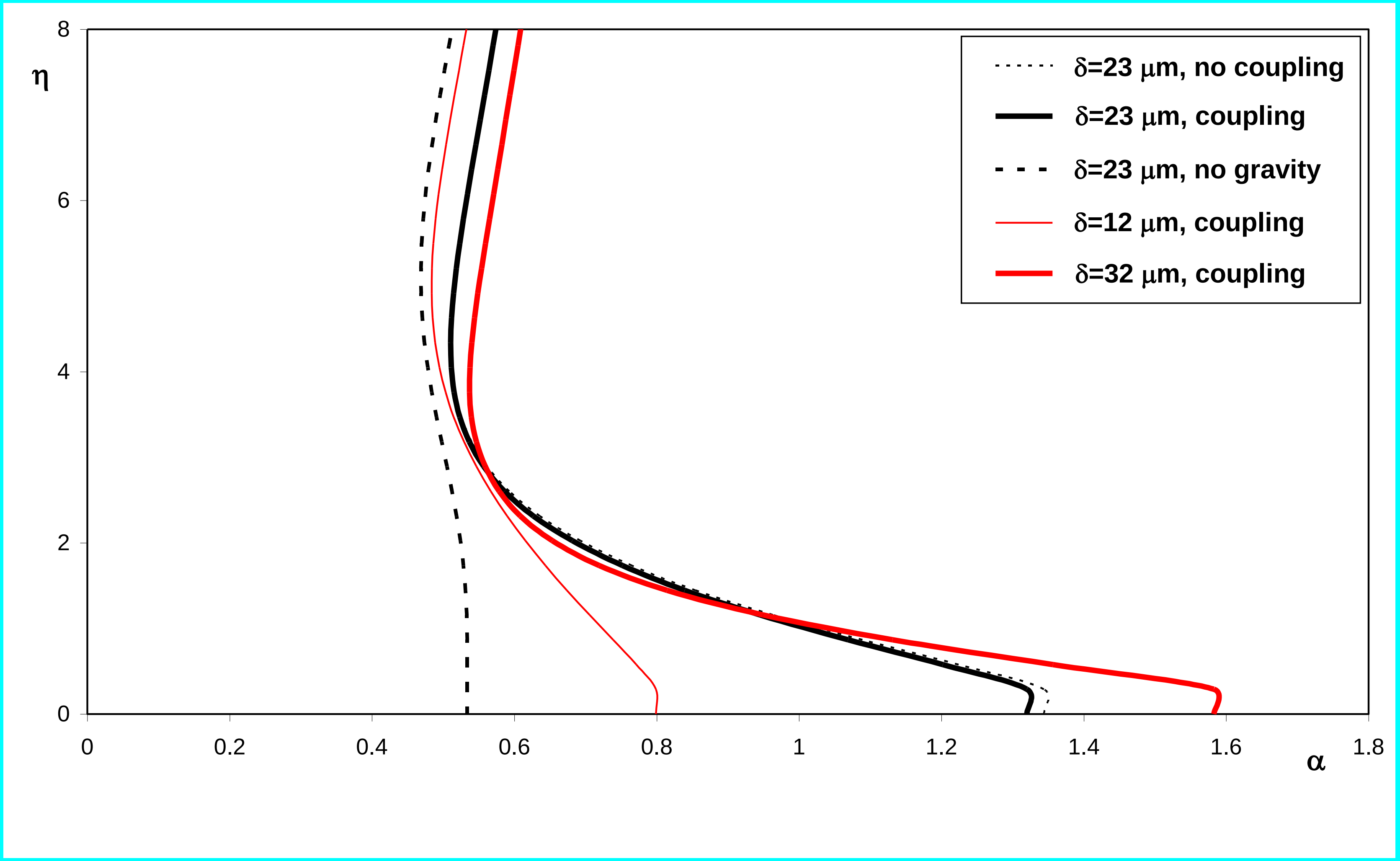
Profiles of transversal slip velocity normalized to friction velocity; æ=0.07, x=0.4



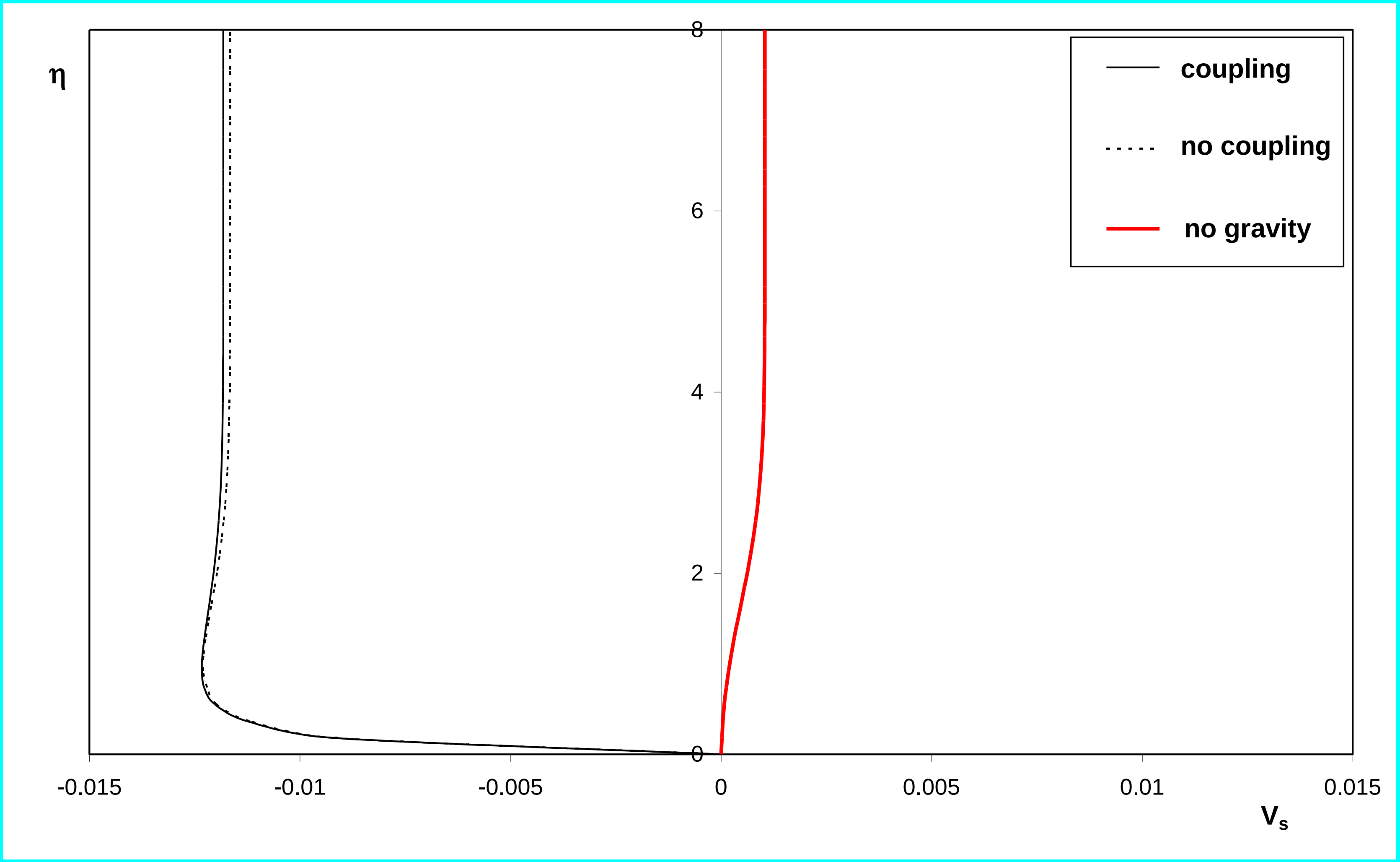
Profiles of axial velocities of gas and solid phases across the boundary layer; æ=0.07, x=0.4



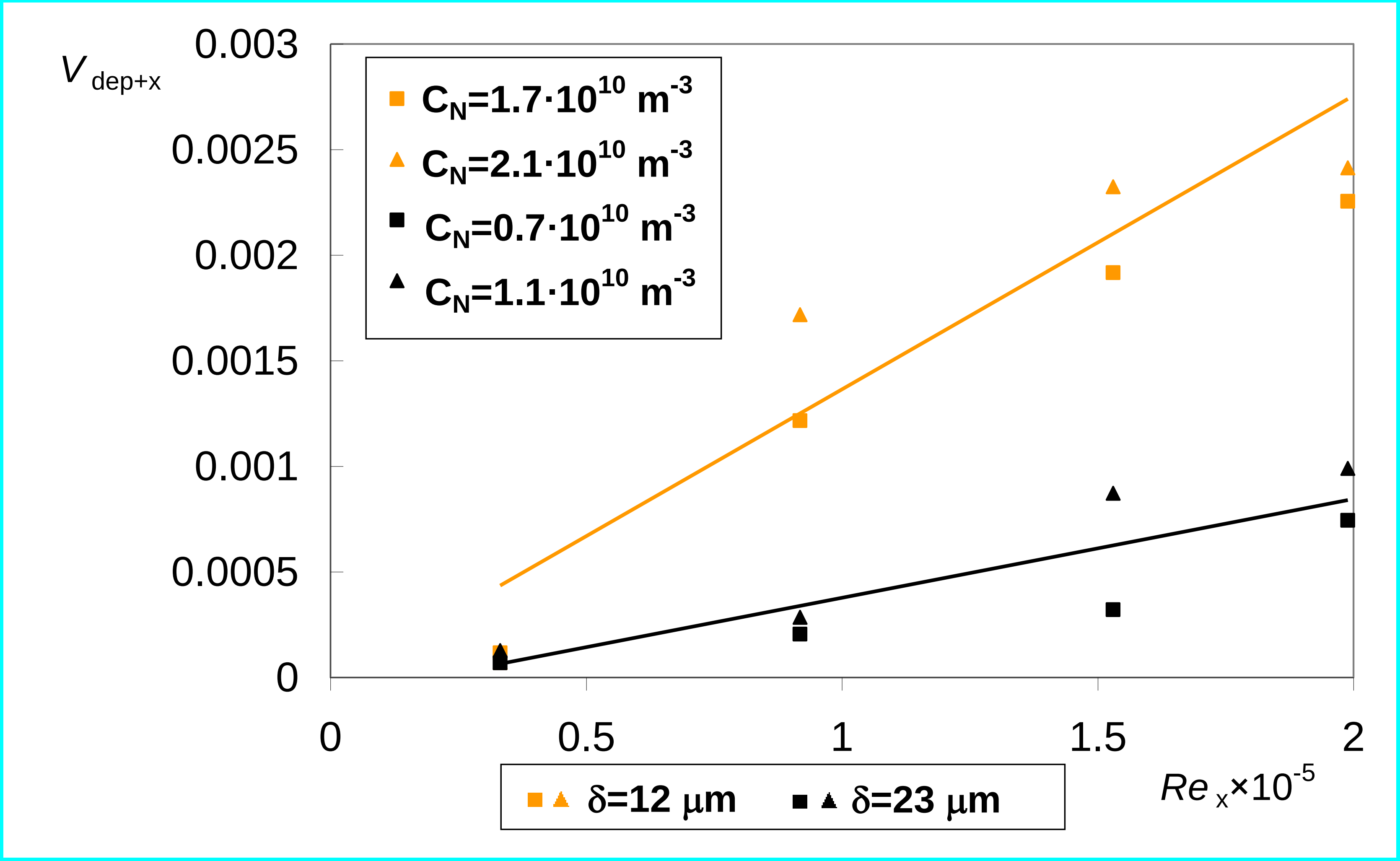
Profiles of particle mass concentration across the boundary layer; æ=0.07, x=0.4



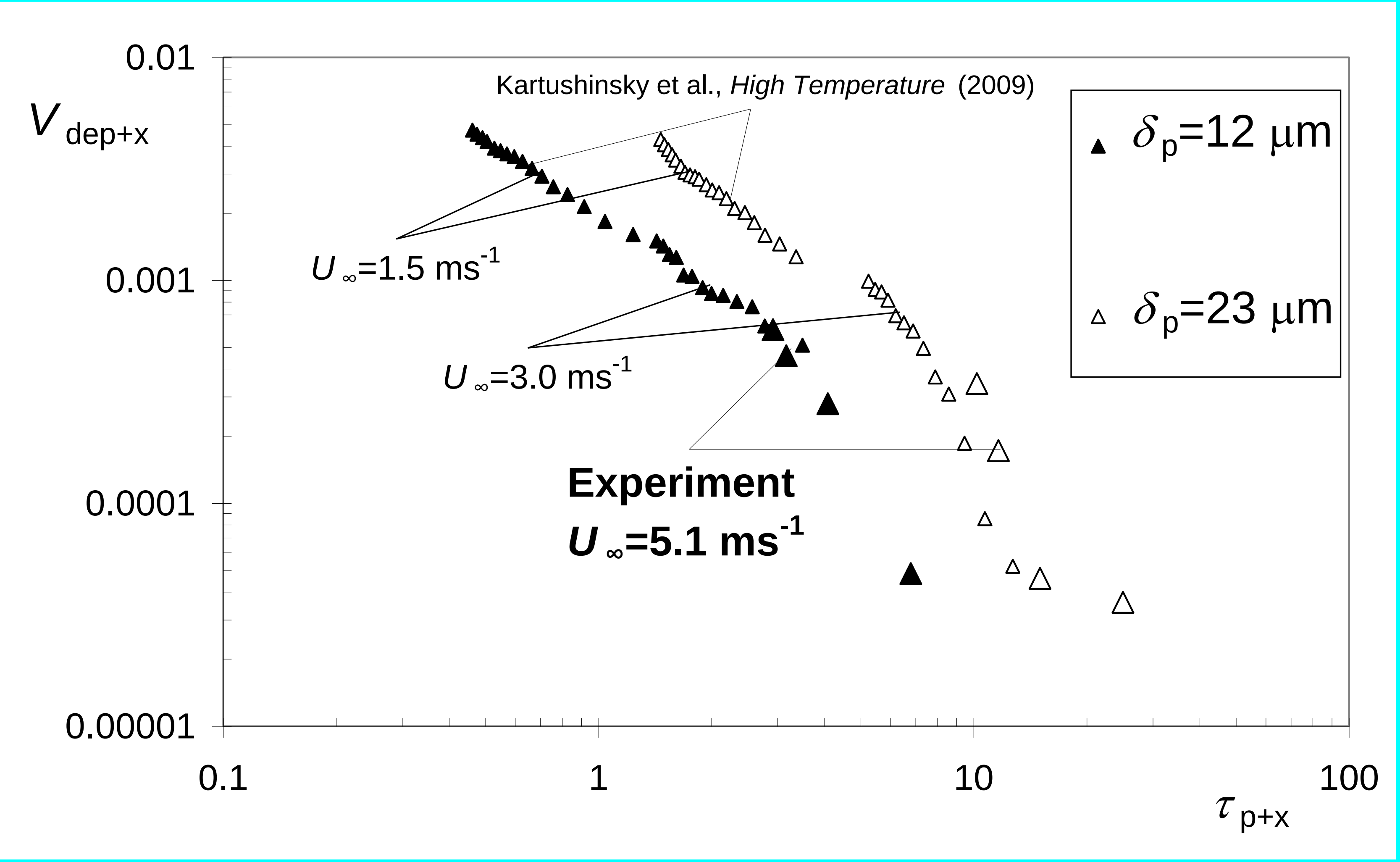
Profiles of transversal velocity of particles across the boundary layer; δ=12 μm, æ=0.07, x=0.99



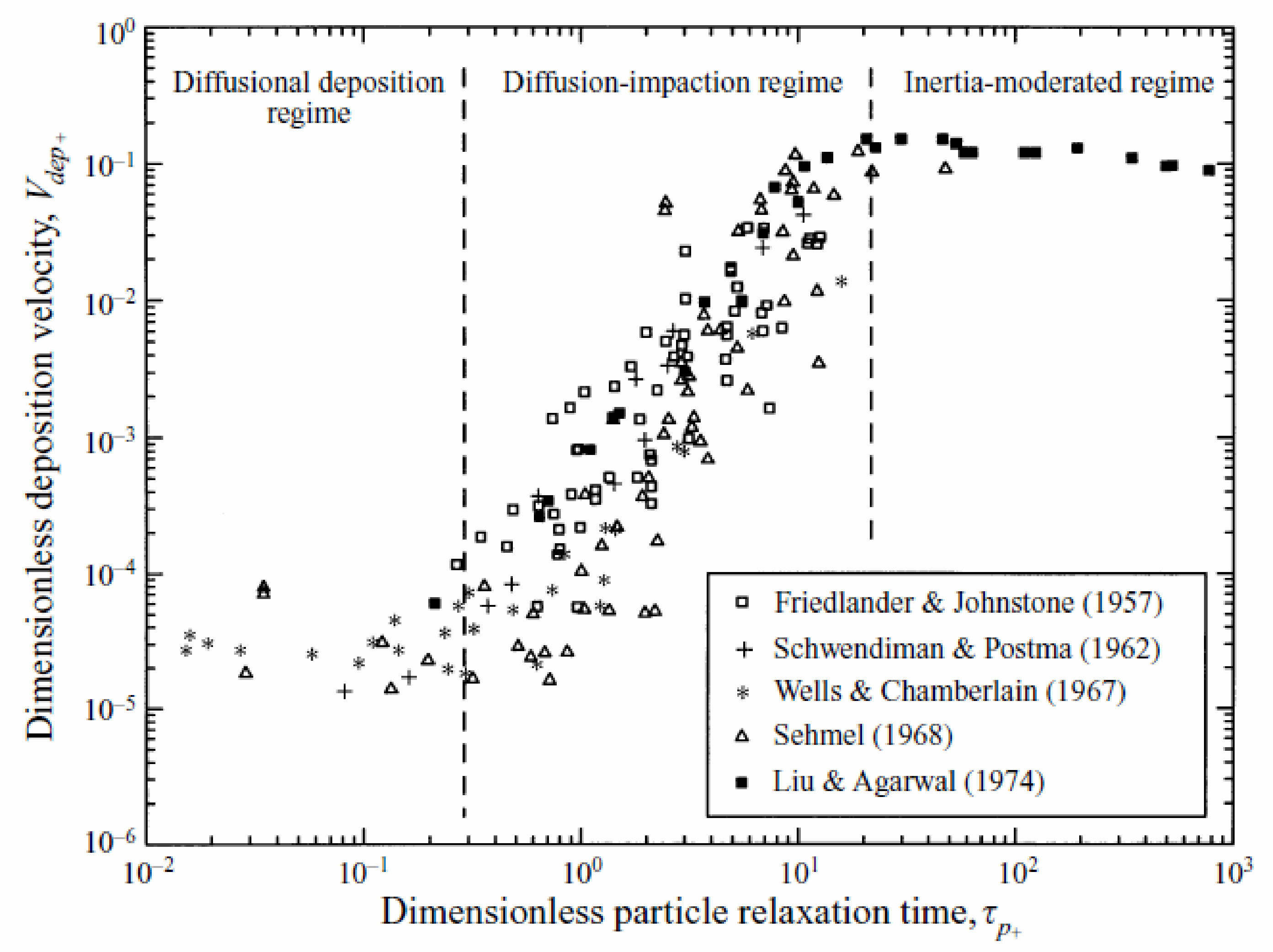
Dimensionless deposition velocity along the flat plate; $U_\infty = 5.1\ ms^{-1}$



Dimensionless deposition velocity *vs* dimensionless relaxation time



Particle deposition from fully developed turbulent pipe flow: a summary of experimental data (Young & Leeming, *J.Fluid Mech.*, 1997)



Conclusions

Two-phase gas-solid particles laminar boundary layer generated near horizontal flat plate was studied for a range of solids loadings and particle sizes. The study shows:

- growth of the particle mass concentration in surface area which increases downward layer; this trend is more pronounced for larger particles.
- particles have velocity lag in x- and y- directions due to gravity which increased with particle sizes.
- the coupling should be taken into account, and its contribution increases with mass loading.
- the shape factor may have a noticeable impact onto the flow conditions.