Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)

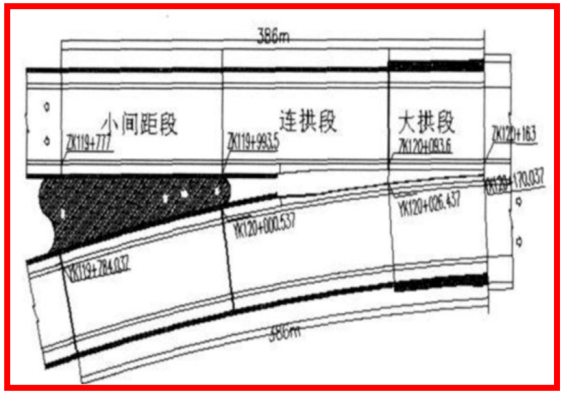
Local loss model of dividing flow in a bifurcate tunnel with a small angle

Key words: Bifurcate tunnel; Dividing flow; Local loss mechanism; Flow separation characteristics; Computational fluid dynamics (CFD); Theoretical formula

Cite this as: Xin ZHANG, Tian-hang ZHANG, Yun-ge HOU, Kai ZHU, Zhi-yi HUANG, Ke WU, 2019. Local loss model of dividing flow in a bifurcate tunnel with a small angle. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 20(1):21-35.

https://doi.org/10.1631/jzus.A1800298

Research status and existing problems



To ensure smooth traffic flow at the intersection and improve safety and ride comfort

↓

the radius of curvature at the intersection of the mainline tunnel and the ramp should not be too small

↓

many bifurcate tunnels with a small bifurcation angle exist

Hager, 2010	sudden change of the tunnel shape → **changes in velocity, direction and distribution of the flow**, during the change of flow pattern, intense friction and momentum exchange occur among fluid particles, **causing local energy loss**
Li ling et al., 2001	bifurcate structure with an angle of **64°**
IWANAMI et al., 1969	bifurcate structure with an angle of **90°**
Miller, 1971; American Society Of Heating, 1989	area ratio, diversion ratio, the angle between two branches, Reynolds number (*Re*), chamfer, the cross-sectional shape of the channel
Shi xi et al., 2013	***Re*.** $Re \geq 1.5 \times 10^5$, ξ does not vary with *Re* and depends only on the form of the bifurcate structure;
Itō and Imai, 1973	**Chamfer.** ξ: rounded chamfer < sharp chamfer*(Costa et al., 2006).* larger radius , lower ξ_{13};
Hoffmann et al., 2003	**diversion ratio** and **angle** between two branches have more significant effects on local loss coefficient than **cross-sectional shape**
Idel'chik et al., 2008	ξ and diversion ratio can be related by a second-order parabolic equation. (**45° ~120°**)
Hagar, 1984;Bassett et al., 2001;Oka and Itō, 2005	a theoretical formula for calculating ξ for any diversion ratio and for the angle range of **45° ~120°** .

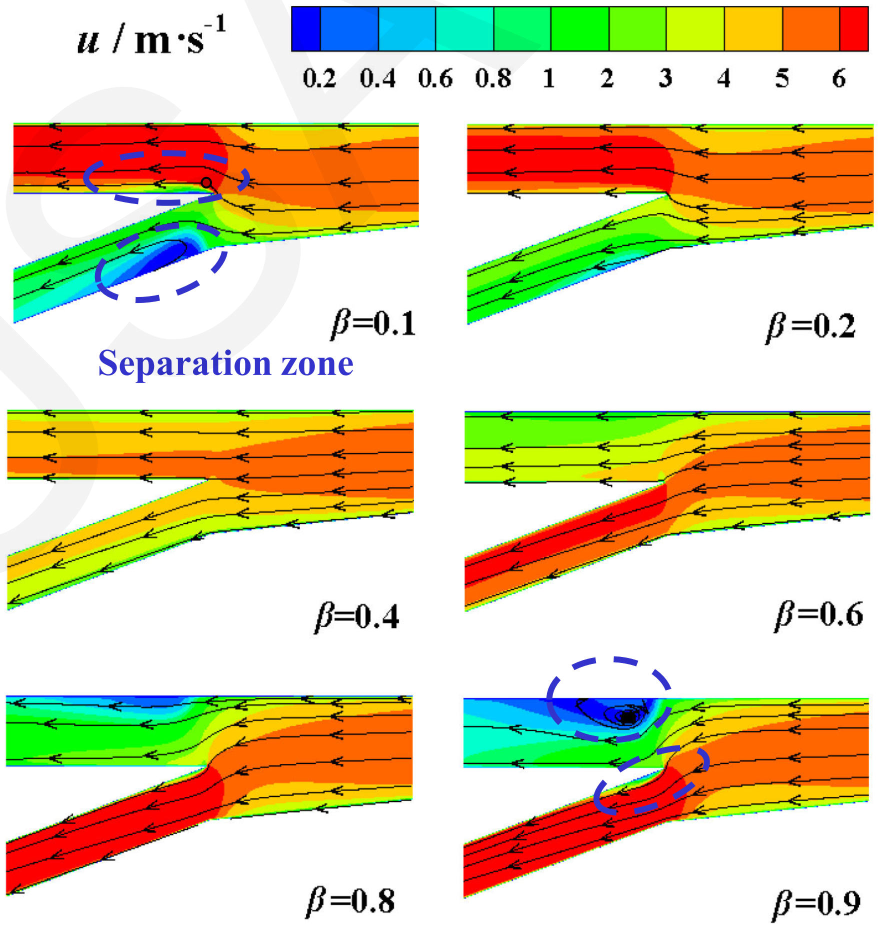
Applicable objects for existing results: $\theta \geq 45°$

Flow characteristics at tunnel bifurcation

- When the diversion ratio *β* is small, the flow is separated on the downstream mainline tunnel sidewall close to the bifurcation point and the ramp sidewall away from bifurcation point

- when *β* is large, the flow is separated on the downstream mainline sidewall away from bifurcation point and the ramp sidewall close to bifurcation point.

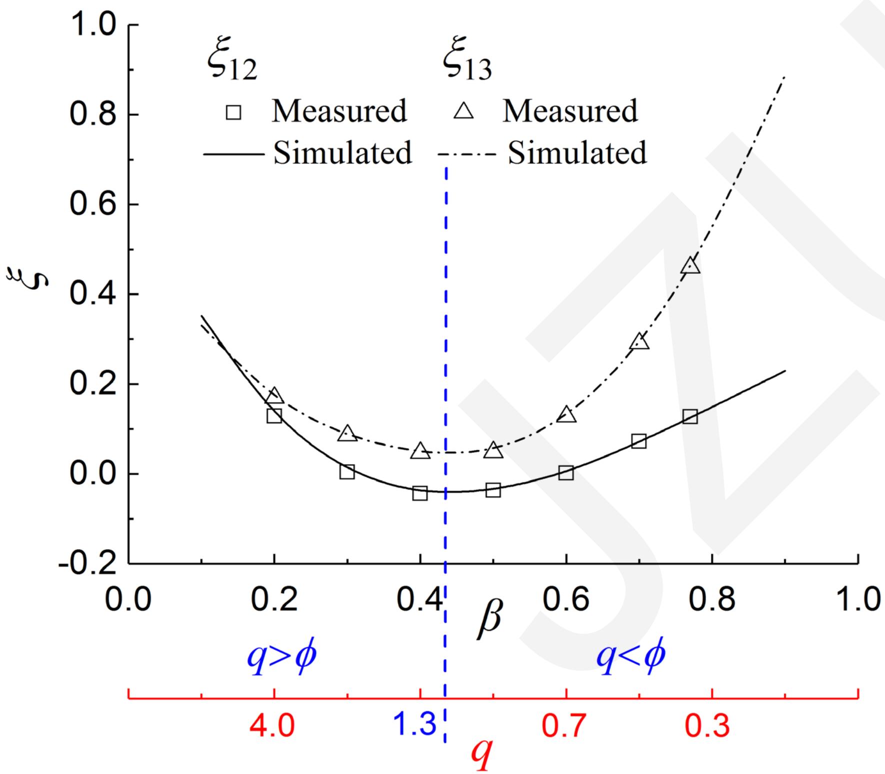
The local losses from flow division are caused mainly by velocity gradient changes and flow deflection and separation



Flow structure of tunnel bifurcation at different β (θ =10°)

The effect law of diversion ratio on local loss coefficients

$$q = \frac{\text{the air flux in the downstream mainline}}{\text{the air flux in the ramp}} \qquad \phi = \frac{\text{cross - sectional area of downstream mainline}}{\text{cross - sectional area of ramp}} = 1.3$$

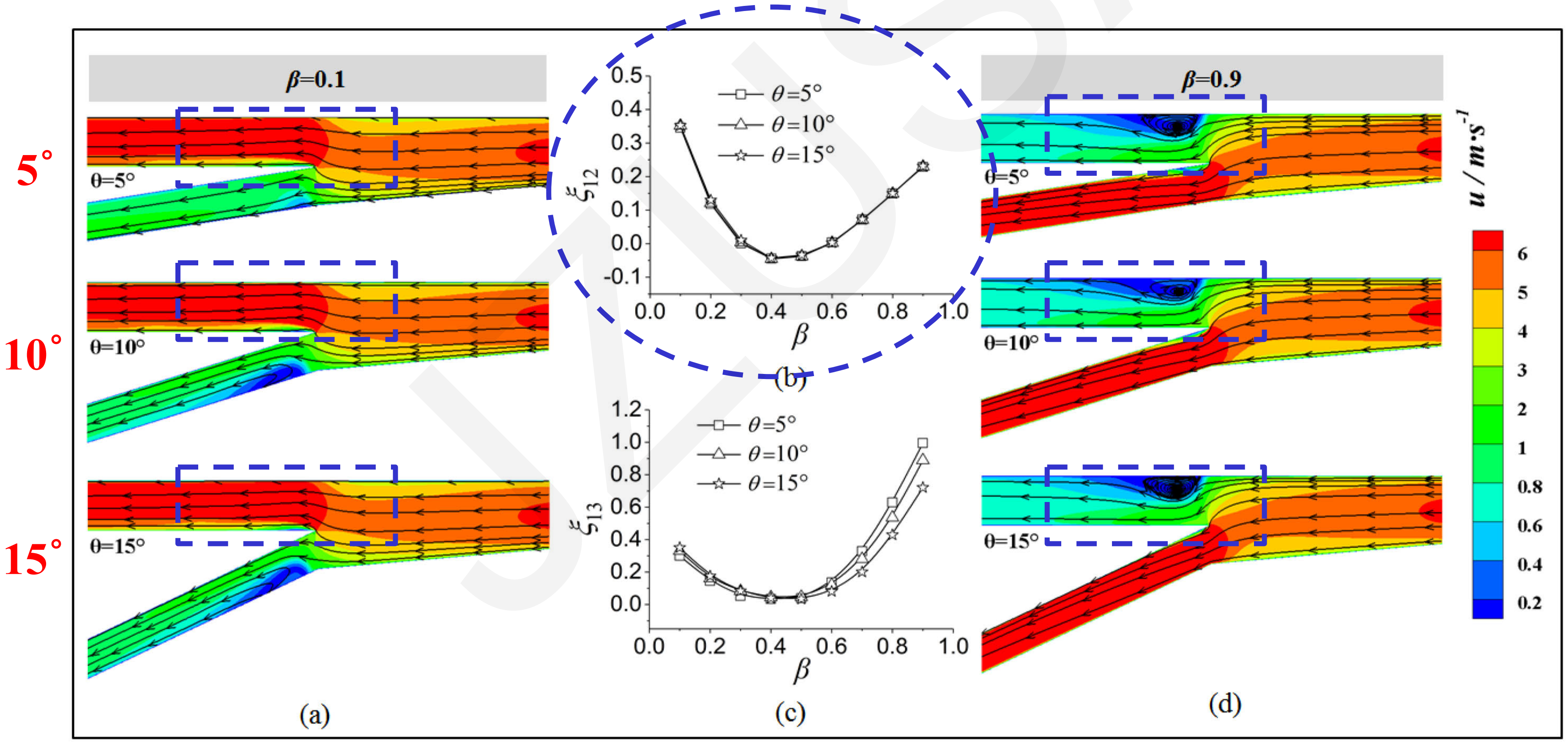


- **$\beta<0.43$ $(q>\phi)$: ξ decrease with the increase of β**
- **$\beta = 0.43$ $(q=\phi)$: ξ_{min}**
- **$\beta >0.43$ $(q<\phi)$: ξ increase with the increase of β**

The mismatch between θ and airflow deflection will strengthen the flow separation and increase the local loss in the ramp

The effect law of bifurcation angle on local loss coefficients

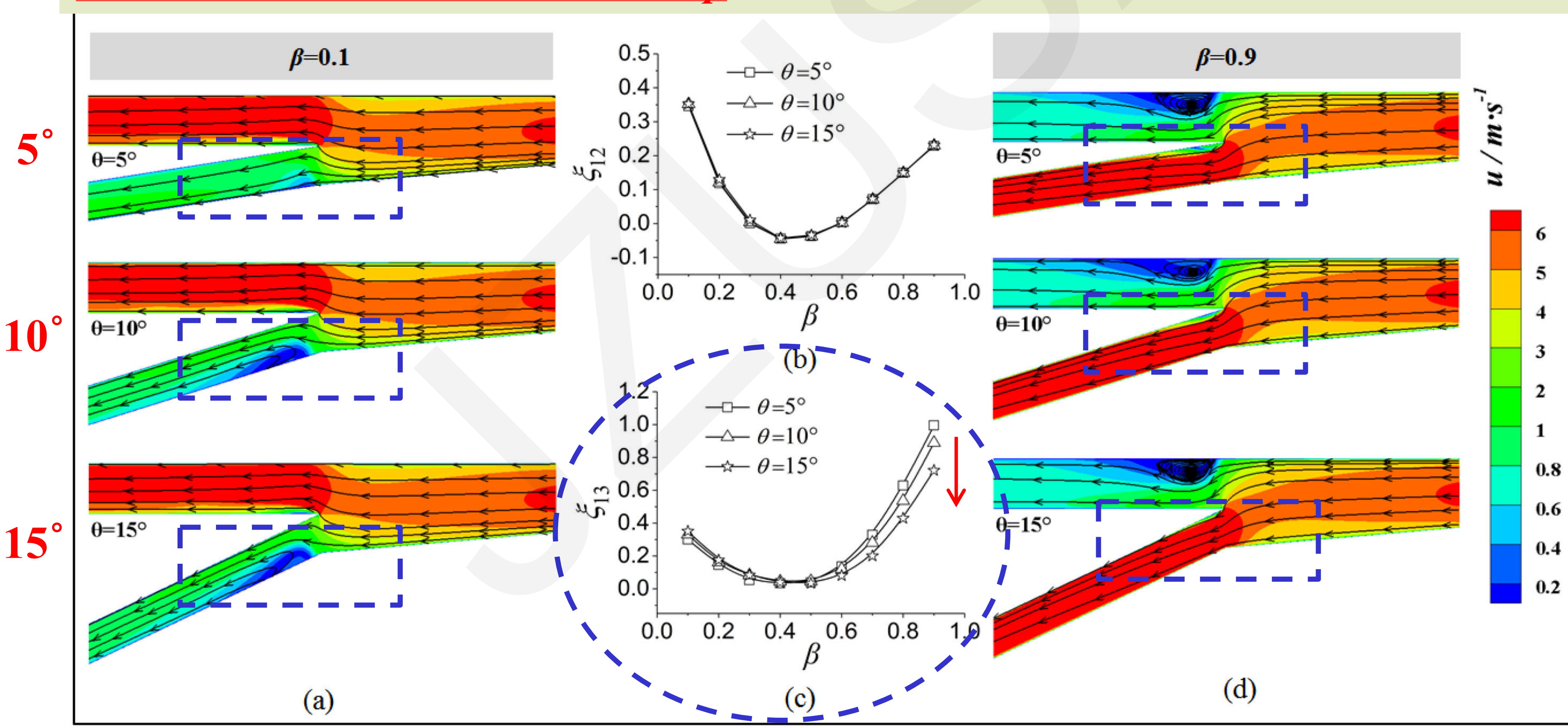
- As for the dividing flow local loss coefficient of the main line, it almost suffers no impacts of the included angle



The effect law of bifurcation angle on local loss coefficients

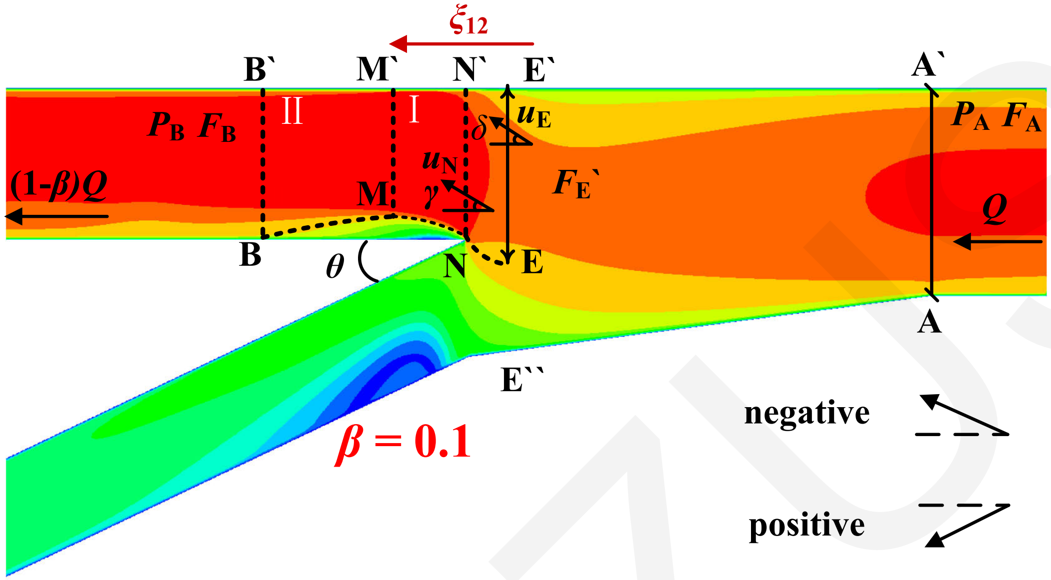
- As for the dividing flow local loss coefficient of ramp, it goes up as θ increases when $q>\phi$, and declines with the increase of θ at $q<\phi$

the mismatch between θ and airflow deflection will strengthen the flow separation and increase the local loss in the ramp



The theoretical formula to predict the dividing flow local loss coefficient

(1) ξ_{12}

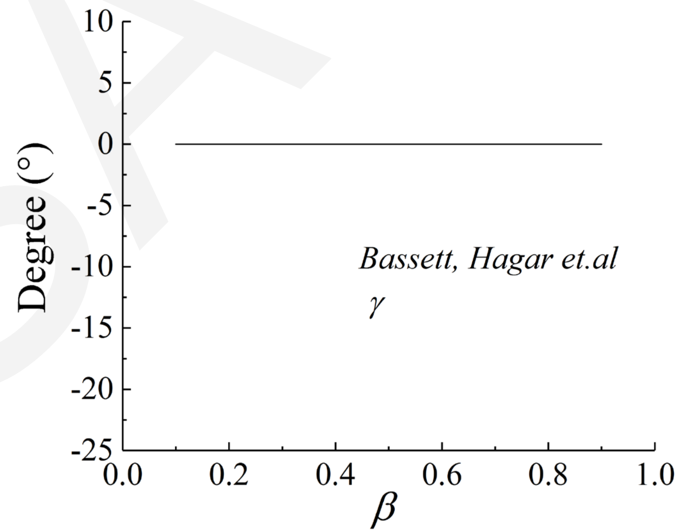


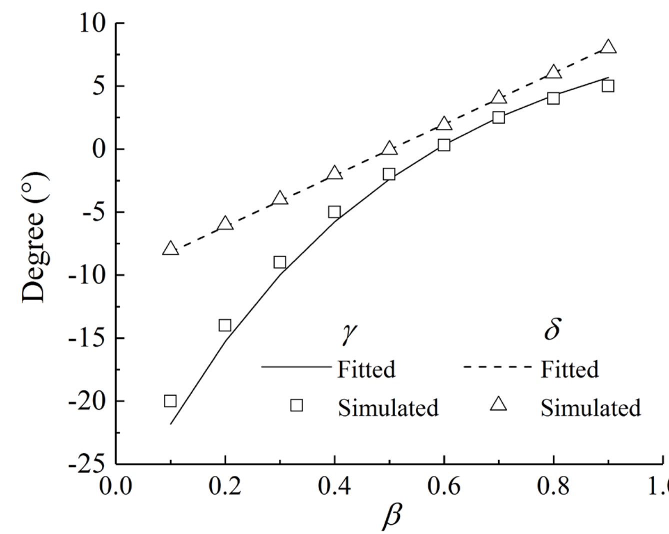
$$\xi_{12}=\left(\frac{F_A}{F_B}\right)^2(1-\beta)^2-\frac{2\cos\gamma F_A^2}{F_B F_E\cos\delta}(1-\beta)+\left(\frac{F_A}{F_E\cos\delta}\right)^2$$

With the least square method, the expressions of γ and δ with β can be fitted (the goodness of fit R^2 is 0.99 for both) as follows:

$$\gamma=-41.3e^{-2.2\beta}+11.4 \qquad \delta=20.3\beta-10.2$$

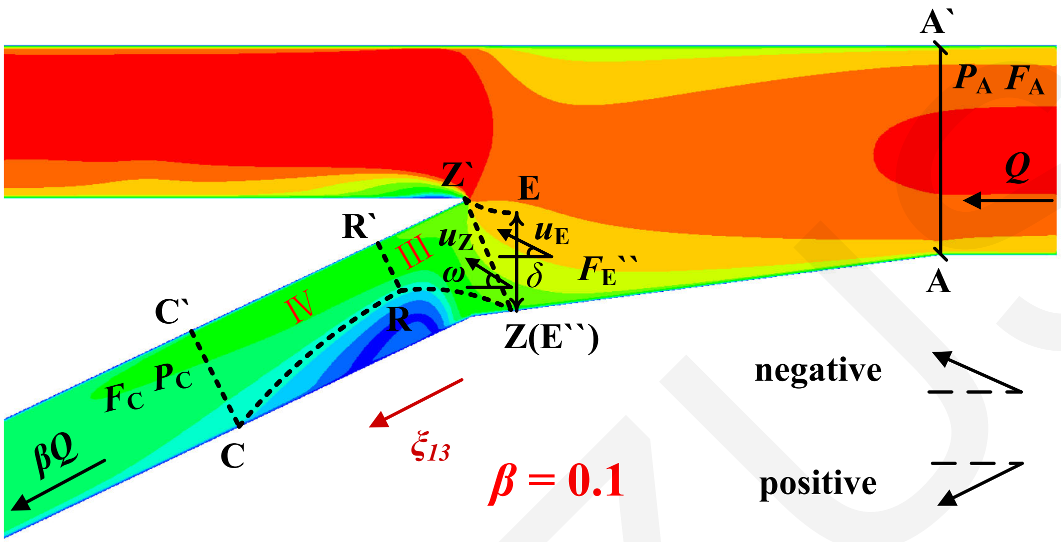
$$\xi_{12}=\left(\frac{F_A}{F_B}\right)^2(1-\beta)^2-\frac{2F_A^2\cos\left(-41.3e^{-2.2\beta}+11.4\right)}{F_B F_E\cos\left(20.3\beta-10.2\right)}(1-\beta)+\left(\frac{F_A}{\cos\left(20.3\beta-10.2\right)F_E}\right)^2$$





The theoretical formula to predict the dividing flow local loss coefficient

(2) ξ_{13}

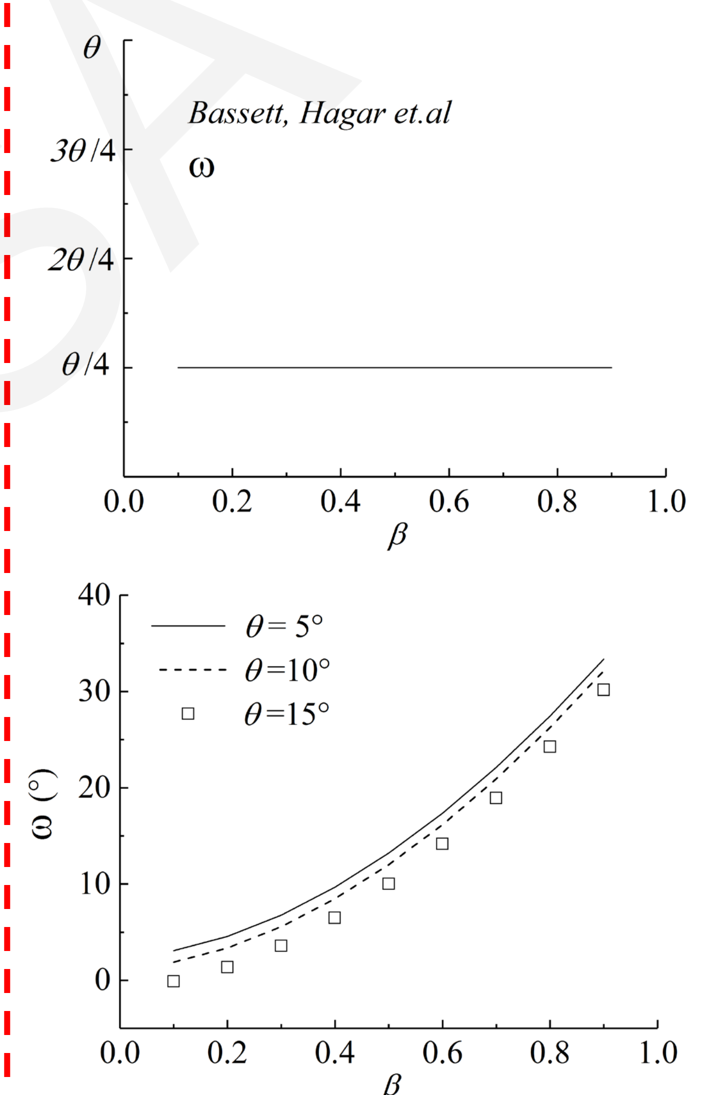


$$\xi_{13}=\left(\frac{F_A}{F_C}\right)^2\beta^2-\frac{2F_A^{\,2}\cos(\theta-\omega)}{F_E F_C\cos\delta}\beta+\left(\frac{F_A}{F_E\cos\delta}\right)^2$$

With the least square method, the expressions of ω and δ with β can be fitted (the goodness of fit R^2 is 0.99 for both) as follows:

$$\omega=37.3\beta^{1.8}\text{-}0.4\theta+5.3 \qquad \delta=20.3\beta\text{-}10.2$$

$$\xi_{13}=\left(\frac{F_A}{F_C}\right)^2\beta^2-\frac{2F_A^{\,2}\cos\left(1.4\theta-37.3\beta^{1.8}-5.3\right)}{F_E F_C\cos(20.3\beta\text{-}10.2)}\beta+\left(\frac{F_A}{F_E\cos(20.3\beta\text{-}10.2)}\right)^2$$



The theoretical formula to predict the dividing flow local loss coefficient

- Comparison of predicted loss coefficients with measured results