Study on Basic Characteristics of Bladeless Stirrer by CFD Analysis

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Introduction

In recent years, bladeless stirrer different from conventional stirrers have been developed[1]. This stirrer agitates using centrifugal force.

Bladeless stirrer

Advantage

- Less turbulence of the liquid surface
- Small shear force

Disadvantage

- Unsuitable in mixing of high viscosity fluid
- Lower mixing performance than conventional stirrers

Since bladeless stirrers are a new technology developed in recent years, it has not been reported how each factor affects the basic characteristics. Moreover, the power number equation of aladeless Stirrer has not been defined.

Factor

- Stirrer diameter
- Pore size
- Outline shape

⇒

Basic characteristics

- Flow state
- Mixing characteristics
- Power characteristics

Power number equation of conventional stirrers (No baffles): $N_{P0} = \{[1.2\pi^4\beta^2]/[8d^3/(D^2H)]\}f$ [2]

Purpose

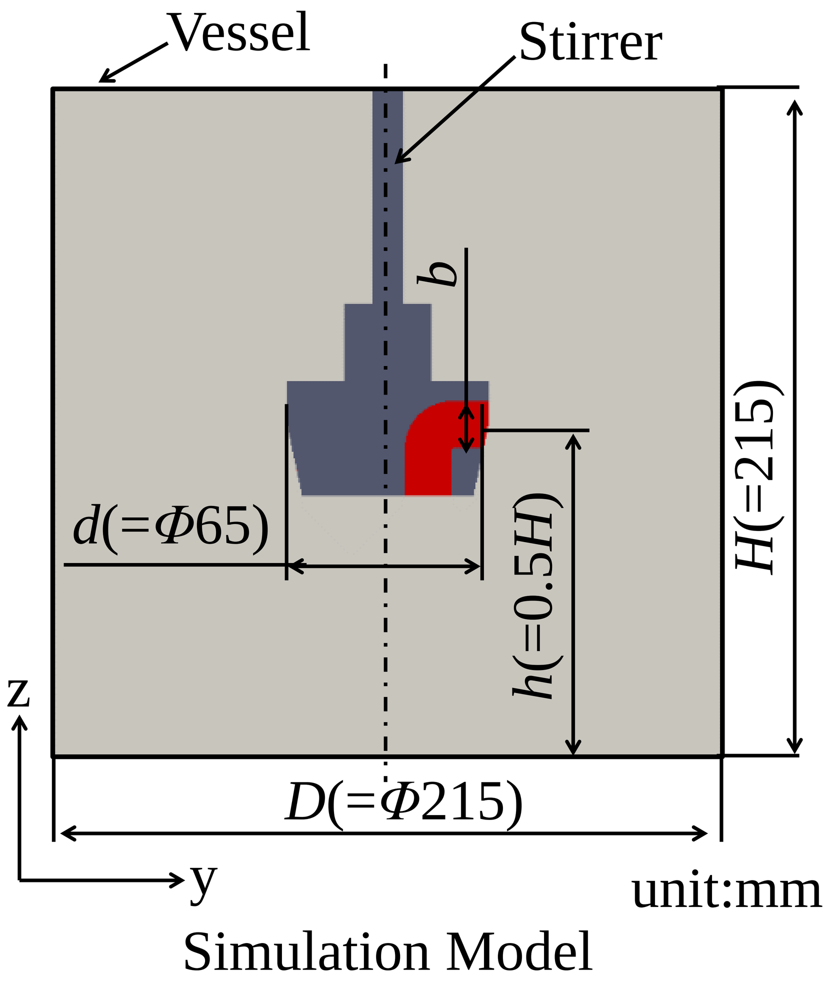
- To investigate the influence of hole size of bladeless stirrer on basic characteristics
- To present the power number equation of blaeless stirrer

Simulation conditions

In this simulation, OpenFOAM[3] is used. In order to use the MRF(Multiple Reference Frame), the analysis region is divided into a stationary region and a rotating region.

	Region	Governing equation	
Navier–Stokes equation	Stationary	$\nabla\cdot(\boldsymbol{u_i}\boldsymbol{u_i}) = -\frac{1}{\rho}\nabla p + \nu\nabla\cdot(\nabla\boldsymbol{u_i})$	(1)
	Rotating	$\nabla\cdot(\boldsymbol{u_r}\boldsymbol{u_i}) + \boldsymbol{\Omega}\times\boldsymbol{u_i} = -\frac{1}{\rho}\nabla p + \nu\nabla\cdot(\nabla\boldsymbol{u_i})$ [4]	(2)
Continuity equation	Stationary & Rotating	$\nabla\cdot\boldsymbol{u_i} = 0$	(3)

$\boldsymbol{u_i}$:Velocity(stationary region), $\boldsymbol{u_r}$:Velocity(rotating region), $\boldsymbol{\Omega}$:Acceleration
p:Pressure, ρ:Density, ν:Kinematic viscosity coefficient $\boldsymbol{u_i} = \boldsymbol{u_r} + \boldsymbol{\Omega}\times\boldsymbol{r}$

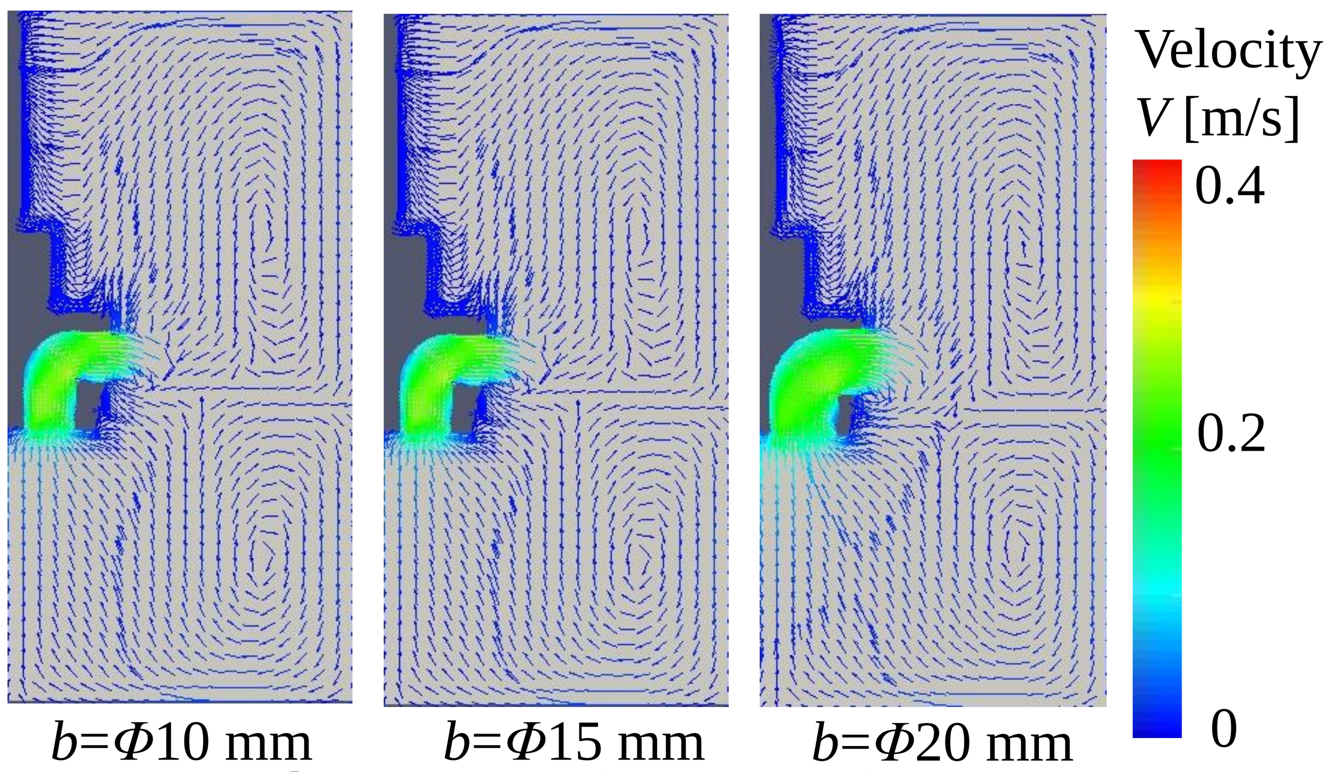


Simulation Model

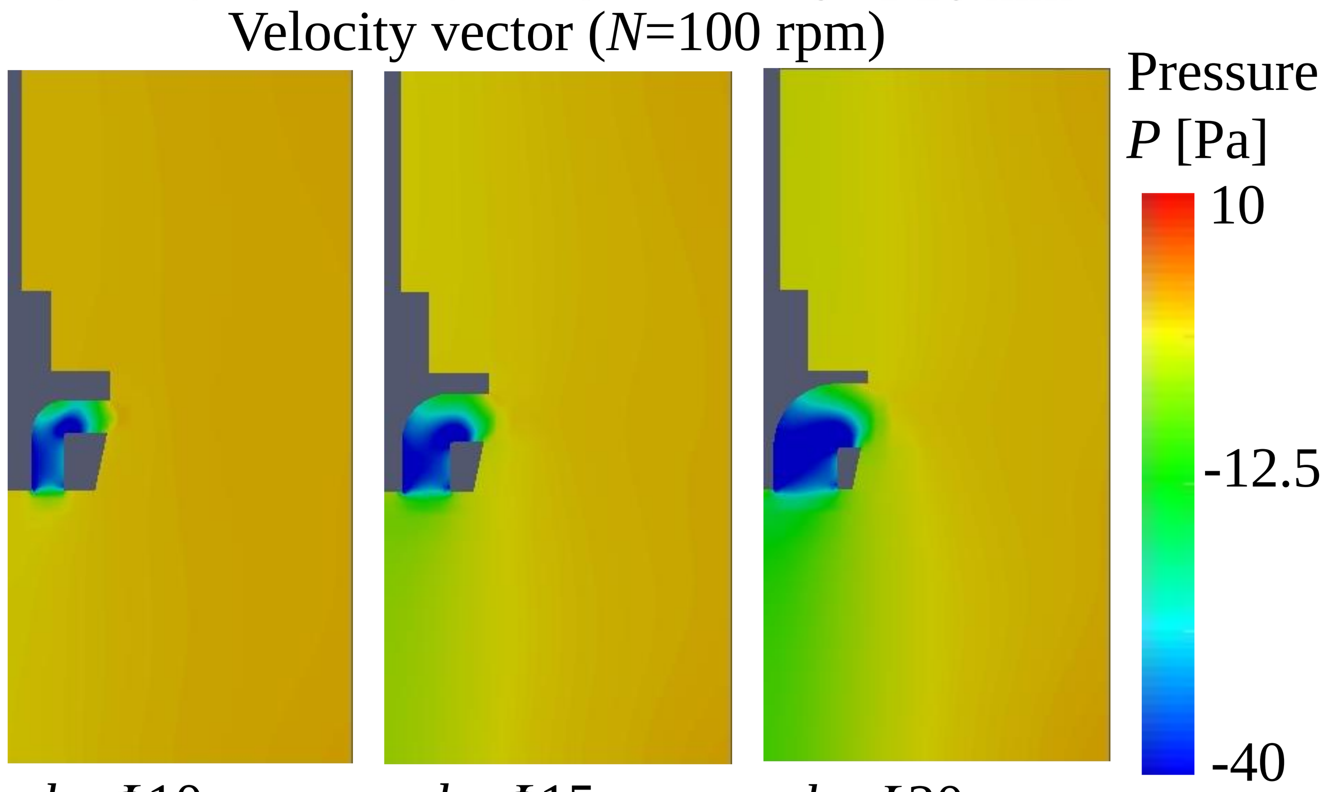
Simulation conditions

Pore size b [mm]	Φ10, Φ15, Φ20
Rotation speed N [rpm]	100, 200, 300, 400, 500, 600, 700, 800, 900, 1000
Kinematic viscosity coefficient ν [m²/s]	1.0×10^{-6}
Density ρ [kg/m³]	1000
Number of hole n [-]	3

Simulation Results



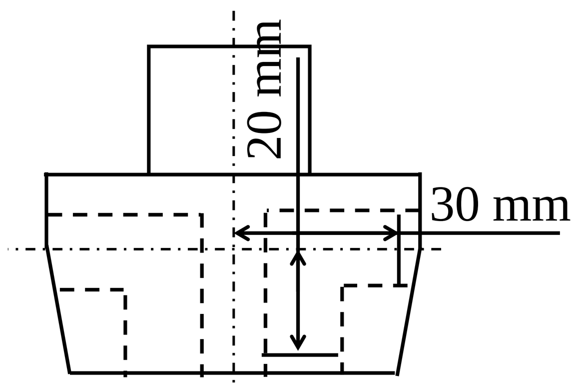
b=Φ10 mm b=Φ15 mm b=Φ20 mm
Velocity vector (N=100 rpm)

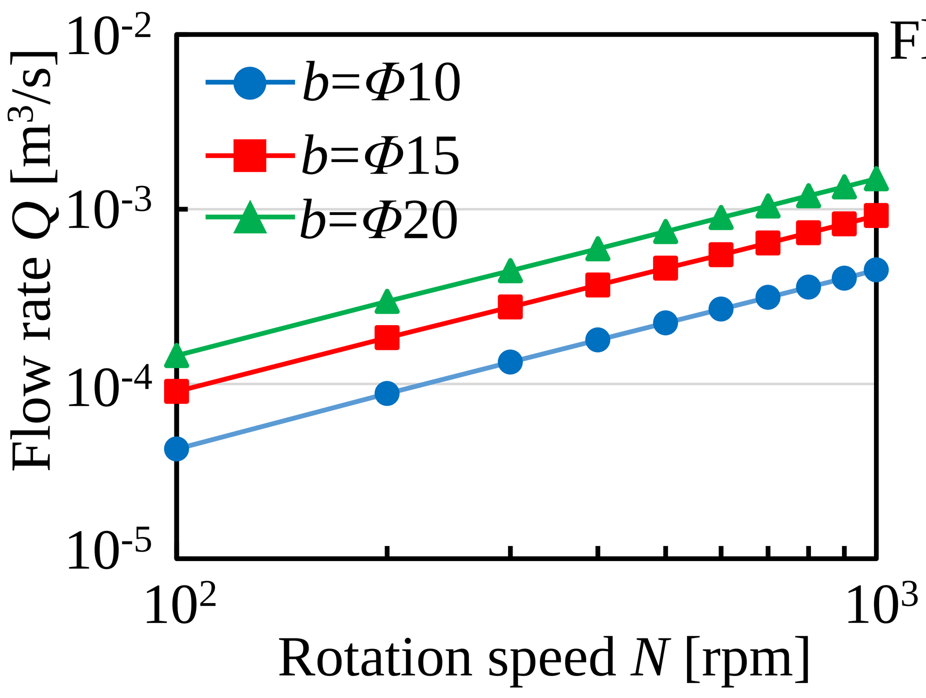


b=Φ10 mm b=Φ15 mm b=Φ20 mm
Pressure distribution (N=100 rpm)

$$P=\rho Q\{\frac{1}{\rho}(p_{out}-p_{in})\} = Q\Delta p \quad (4)$$

$$Q = nAw_{out}$$
$$\Delta p = p_{out} - p_{in}$$





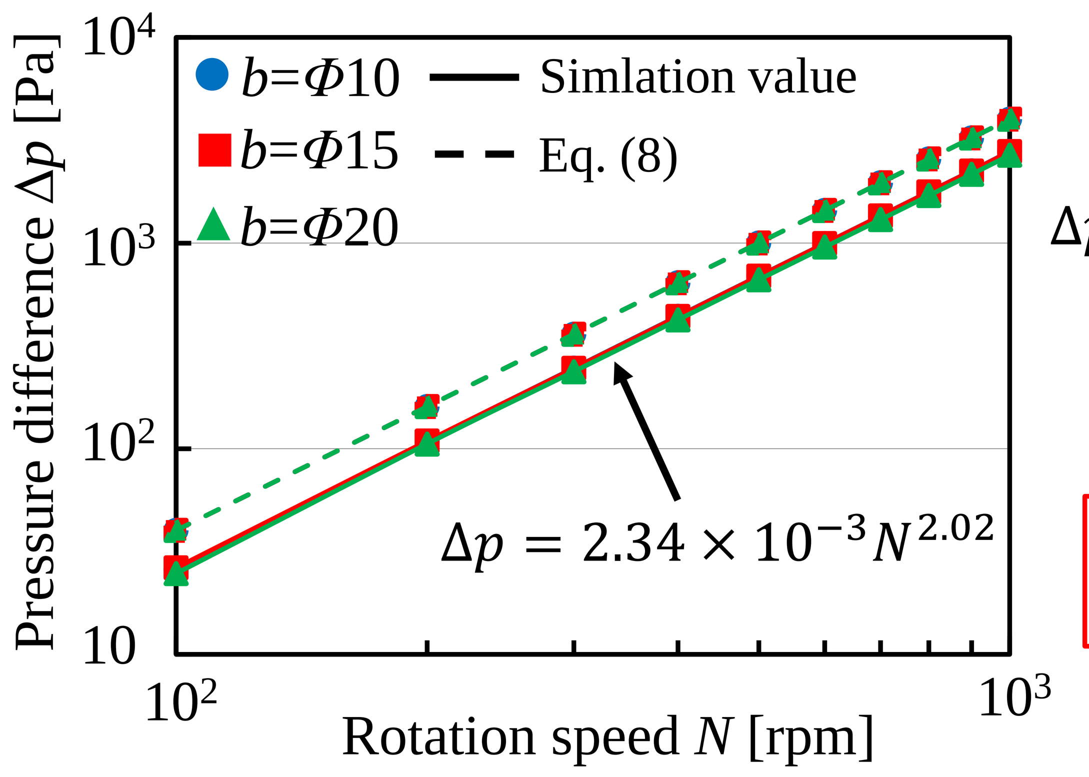
Flow coefficient

$$C = \frac{Q}{Aw_{out}} \quad (5)$$

C=0.6 (b=Φ10)
0.55(b=Φ15)
0.5 (b=Φ20)

$$Q = \frac{1}{120}C\pi^2b^2nNr_{out} \quad (6)$$

(r_{out}:Distance from center)



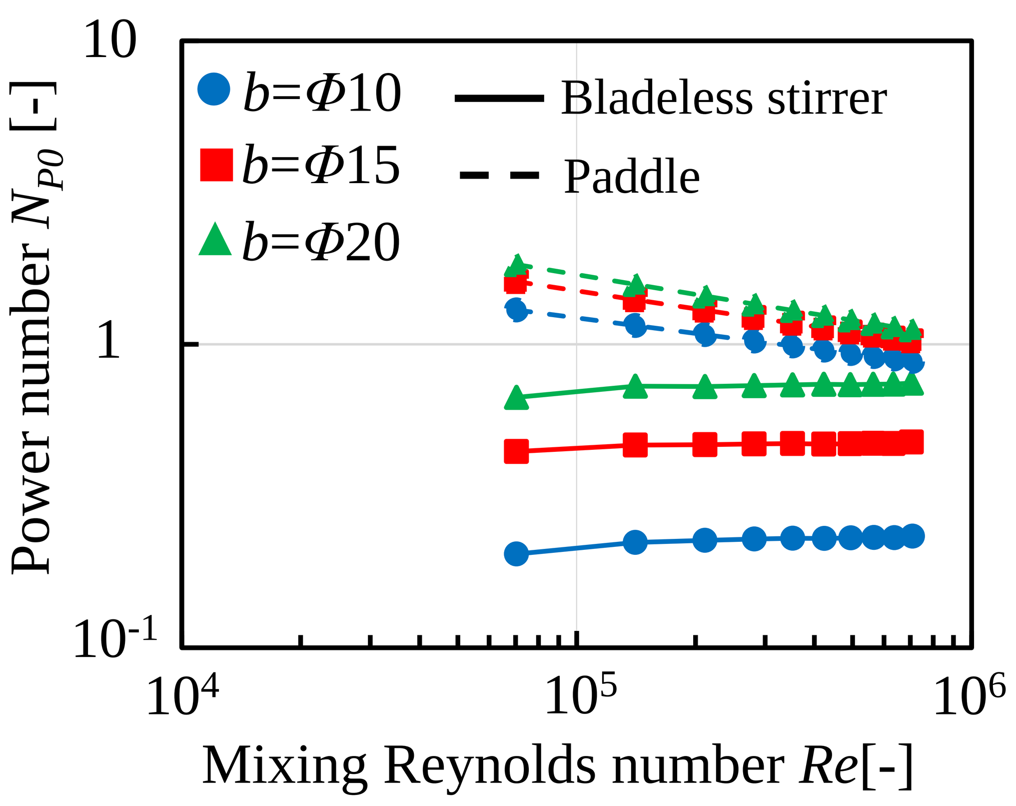
$$\Delta p = \underbrace{\frac{1}{2}\rho(u_{out}^2 - u_{in}^2)}_{\text{Centrifugal force}} + \underbrace{\frac{1}{2}\rho(w_{in}^2 - w_{out}^2)}_{\text{Change in cross section}} \quad (7)$$

$$\Delta p = \frac{1}{2}\rho(u_{out}^2 - u_{in}^2) = \frac{1}{1800}\rho\pi N^2(r_{out}^2 - r_{in}^2) \quad (8)$$

ξ : Entrance loss, ξ_b : Bend loss
λ : Pipe friction coefficient

$$\Delta p = (\xi + \xi_b + \lambda)\frac{1}{1800}\rho\pi N^2(r_{out}^2 - r_{in}^2) \quad (9)$$

$\Rightarrow \Delta p = 2.24\sim2.42\times10^{-3}N^2$

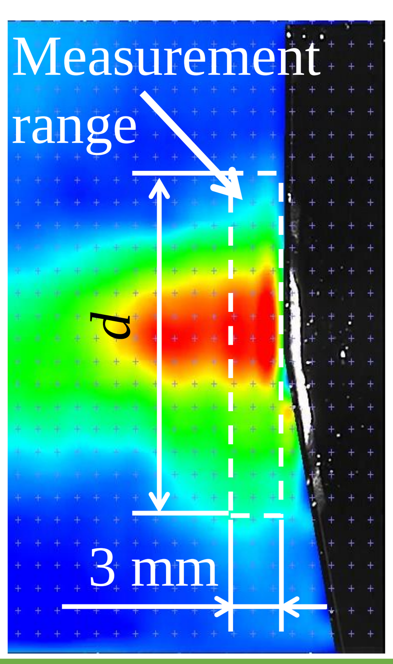


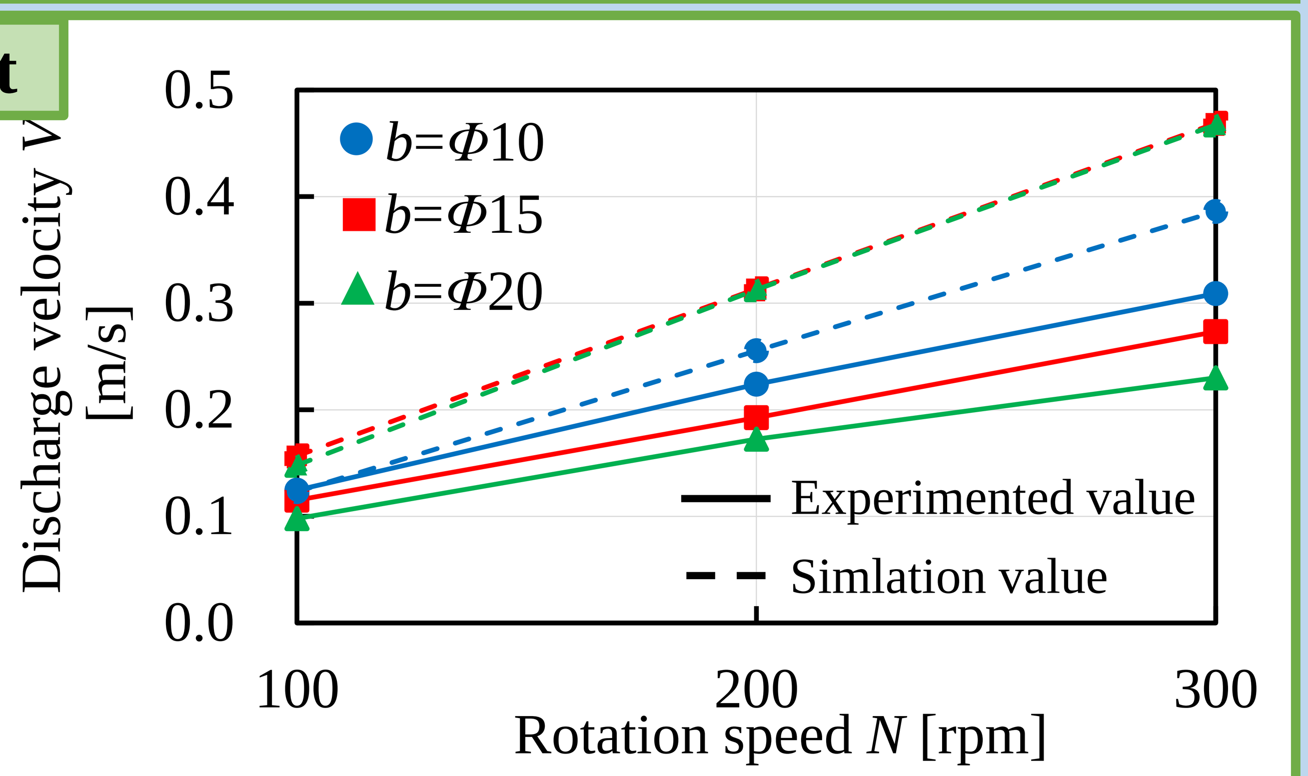
$$N_{p0} = \frac{P}{\rho N^3d^5} = (\xi + \xi_b + \lambda)\frac{1}{d^5}C\pi^4b^2nr_{out}(r_{out}^2 - r_{in}^2) \quad (10)$$

Comparison of simulation and experiment

Experimental conditions

Particle	Diaion(CHP20)
Particle size[μm]	75〜100
Specific gravity[-]	1.02
Rotation speed N [rpm]	100, 200, 300
Frame rate [fps]	1500, 3000, 4500





Conclusions

- The pressure difference of the bladeless stirrer is proportional only to the rotational speed, and does not depend on the hole size.
- Power number equation of bladeless stirrer is presented.

References

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[2] 化学工学会編, 最新 ミキシング技術の基礎と応用，三恵社 (2010), 16
[3] 一般社団法人 オープンCAE学会，OpenFOAMによる熱移動と流れの数値解析，森北出版 (2016)，1
[4] R. Mehdipour，Simulating propeller and Propeller-Hull Interaction in OpenFOAM，Sweden Royal Institute of Technology(2013)，7