Enhanced Heat Transfer for FLiBe Blanket System Using Swirl Flow Method

S. Toda
H. Hashizume

Tohoku University

1. Introduction

Development of high heat flux components

↓

Swirl tube

Factors of heat transfer enhancement

✧ Increase in mass flow rate

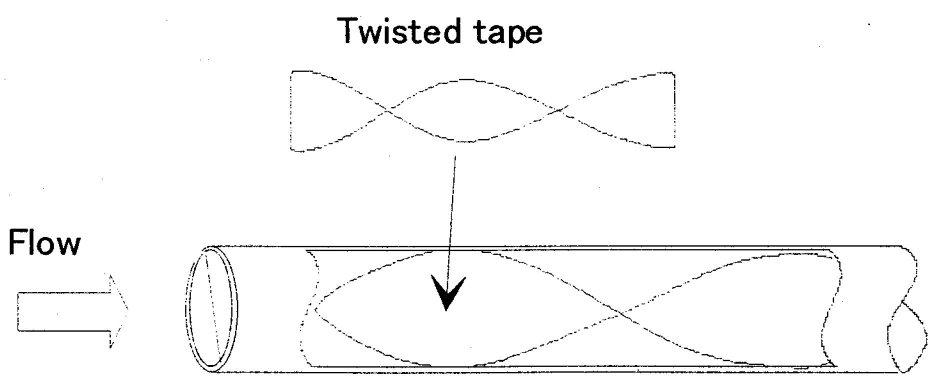
✧ Increase in wetted area

✧ Increase in relative velocity

✧ Heat transfer effect by secondary flow

✧ Fin effect by the tape

✧ Prevention of heat load concentration by swirling flow



2.Objective

Heat transfer enhancement in swirl pipe flow is several times compared with smooth pipe.

↓

Analogy estimation is insufficient for cooling performance.

↓

<u>It is difficult to predict cooling performance.</u>

The reasons are as follows.

- ✧ Scale effect of experimental apparatus
  Method of temperature measurement
- ✧ Arrangement method of data
- ✧ Lack of numerical data

Main flow has swirling structure.

↓

Secondary flow → Three dimensional flow

In previous numerical calculations, these complex secondary flows could not be reproduced.

↓

Numerical simulation in laminar flow
(not to use calculation assumptions)

↓

<u>Estimation of effects of the secondary flow on heat transfer enhancement.</u>

- Qualitative estimation of secondary flow
- Quantitative estimation of cooling performance

3. Calculation method

Assumptions

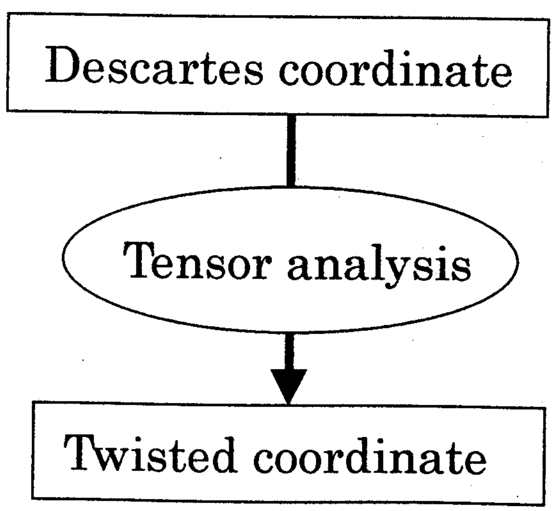
- ✧ Incompressible Newton steady flow
- ✧ Disregard for viscous dissipation
- ✧ Boussinesq approximation

Governed equations

Navier-Stokes equation

Continuity equation

Energy equation



Finite difference method

Control volume method, Power-law scheme,

SIMPLE, Forward difference

Parameters

Re、Pr、Nu、Gr、γ、X

Re : Reynolds number

Pr : Prandtl number

Nu : Nusselt number

Gr : Grashof number

γ : Twist ratio

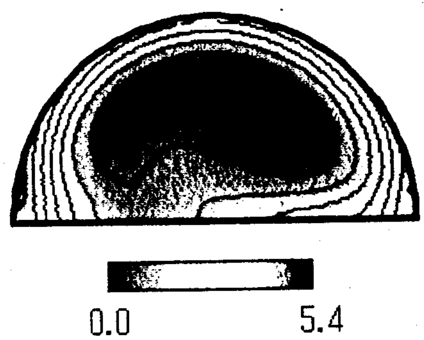
X : Dimensionless distance for axial direction

γ → small ⇒ Highly Twist

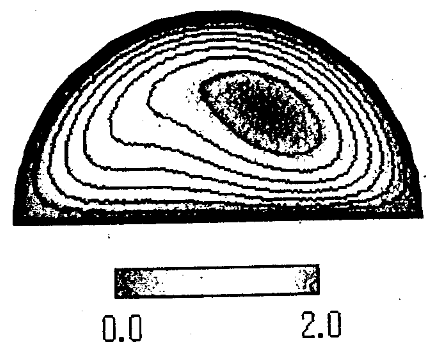
4. Calculation results and consideration

Qualitative estimations of flow field

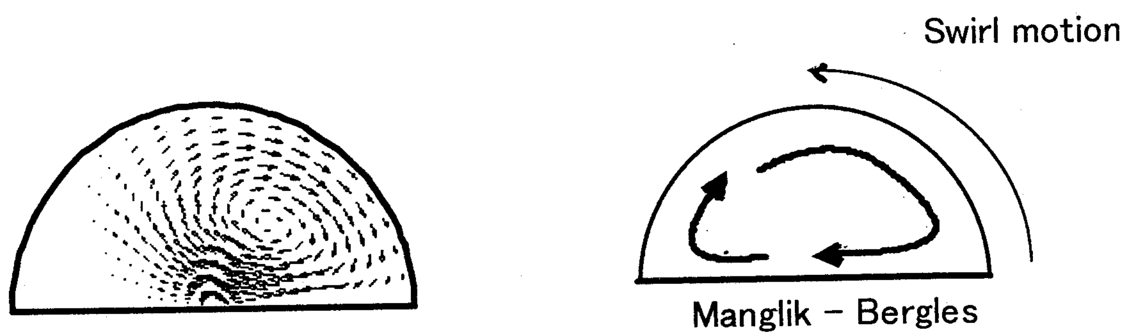
Re =2000、Pr=3、Gr=0、γ =30、X=40



(a) Isothemal map



(b) Axial velocity map



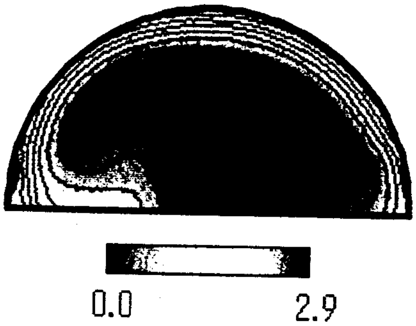
(c) Secondary flow

left: Present result

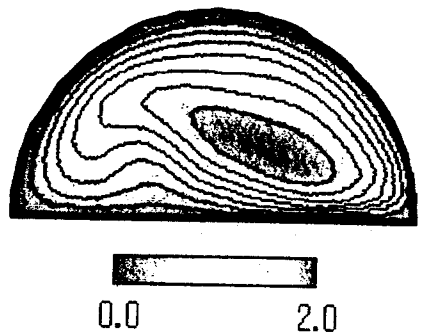
right: By experimental one ($\gamma_0 >> 1$)

Fig.1: Flow pattern of low swirl effect

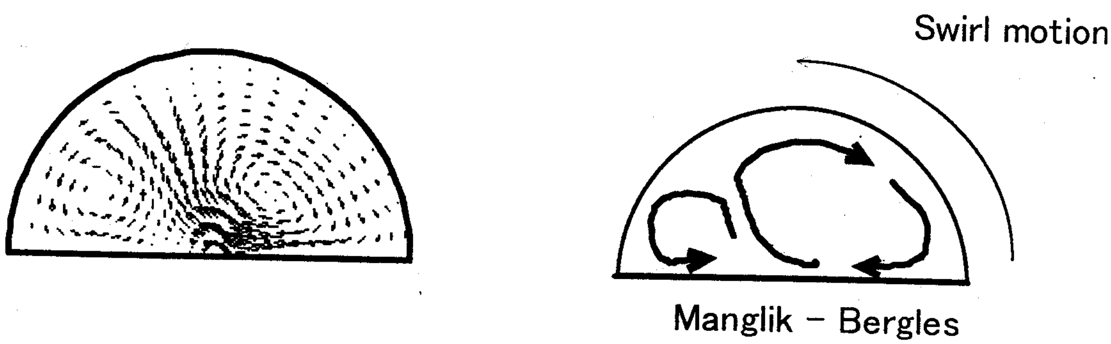
Re =2000、Pr=3、Gr=0、γ =10、X=20



(a) Isothemal map



(b) Axial velocity map



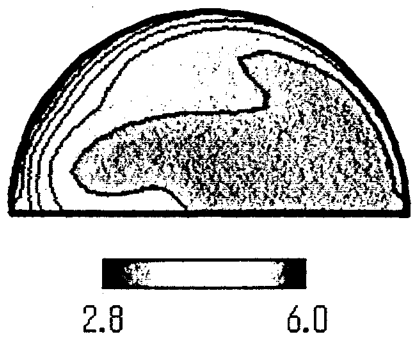
(c) Secondary flow

left: Present result

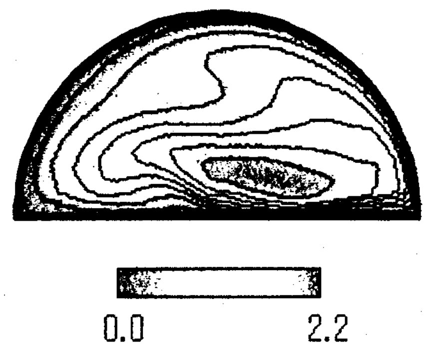
right: By experimental one ($\gamma < \gamma_0$)

Fig.2: Flow pattern of middle swirl effect

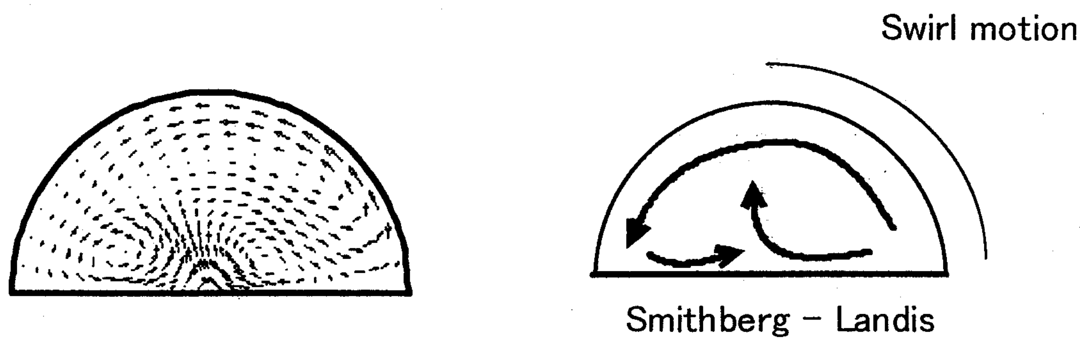
Re =2500、Pr=3、Gr=0、γ =5、X=5



(a) Isothemal map



(b) Axial velocity map



(c) Secondary flow

left: Present result

right: By experimental one (Re=1.4×10^4、γ =10.4)

Fig.3: Flow pattern of high swirl effect

Quantitative estimation for cooling performance

Estimation of averaged Nusselt number
in heated region

$$Nu = 1.058\,Re^{0.27}\,Pr^{0.27} + 0.205\gamma^{-1.52}\,Re^{0.83}\,Pr^{0.38} + 6.05Gr\,Re^{1.65}\,Pr^{0.58}$$

$$Nu_{Hong} = 5.172\left(1 + 5.484\times10^{-3}\,Pr^{0.7}\,Re^{1.25}\,\gamma^{-1.25}\right)^{0.5}$$

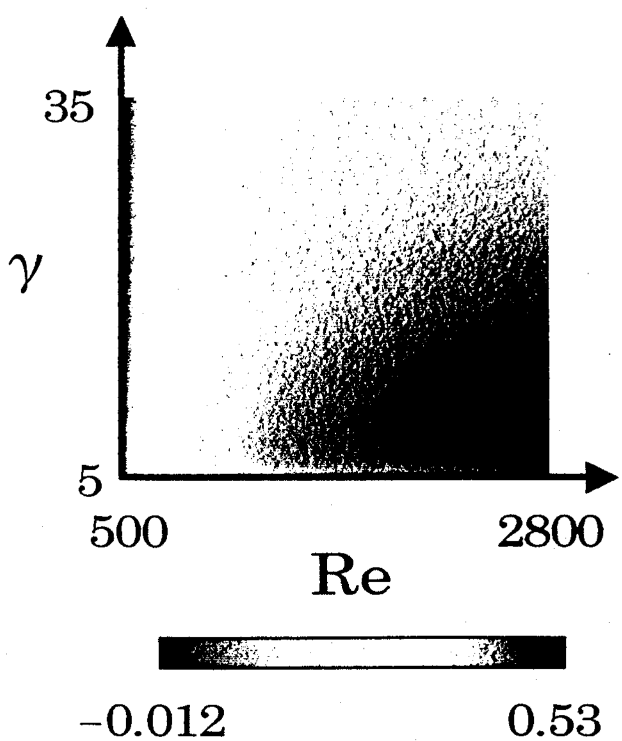


Fig.4: Deviation from Hong's result

($Pr=3$、$Gr=2\times10^{4}$)

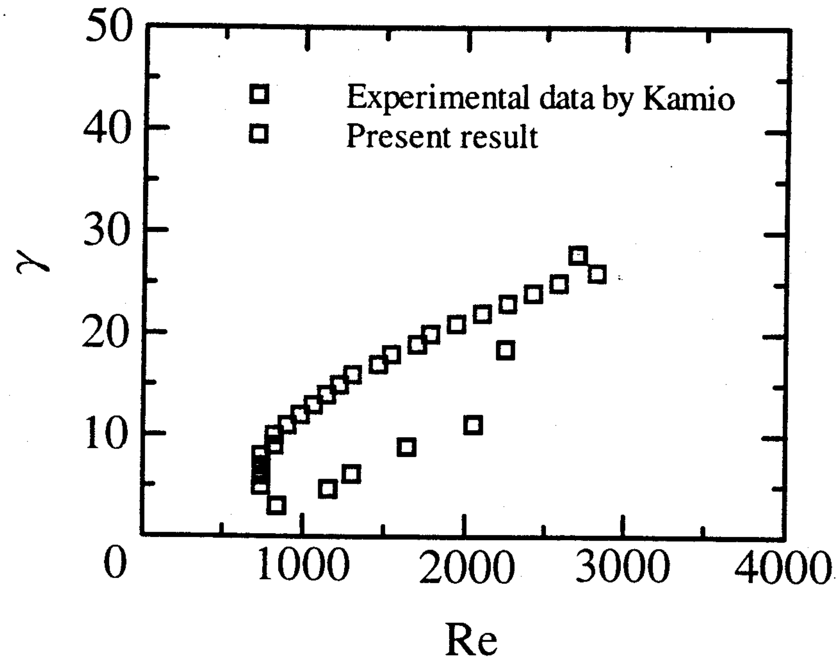
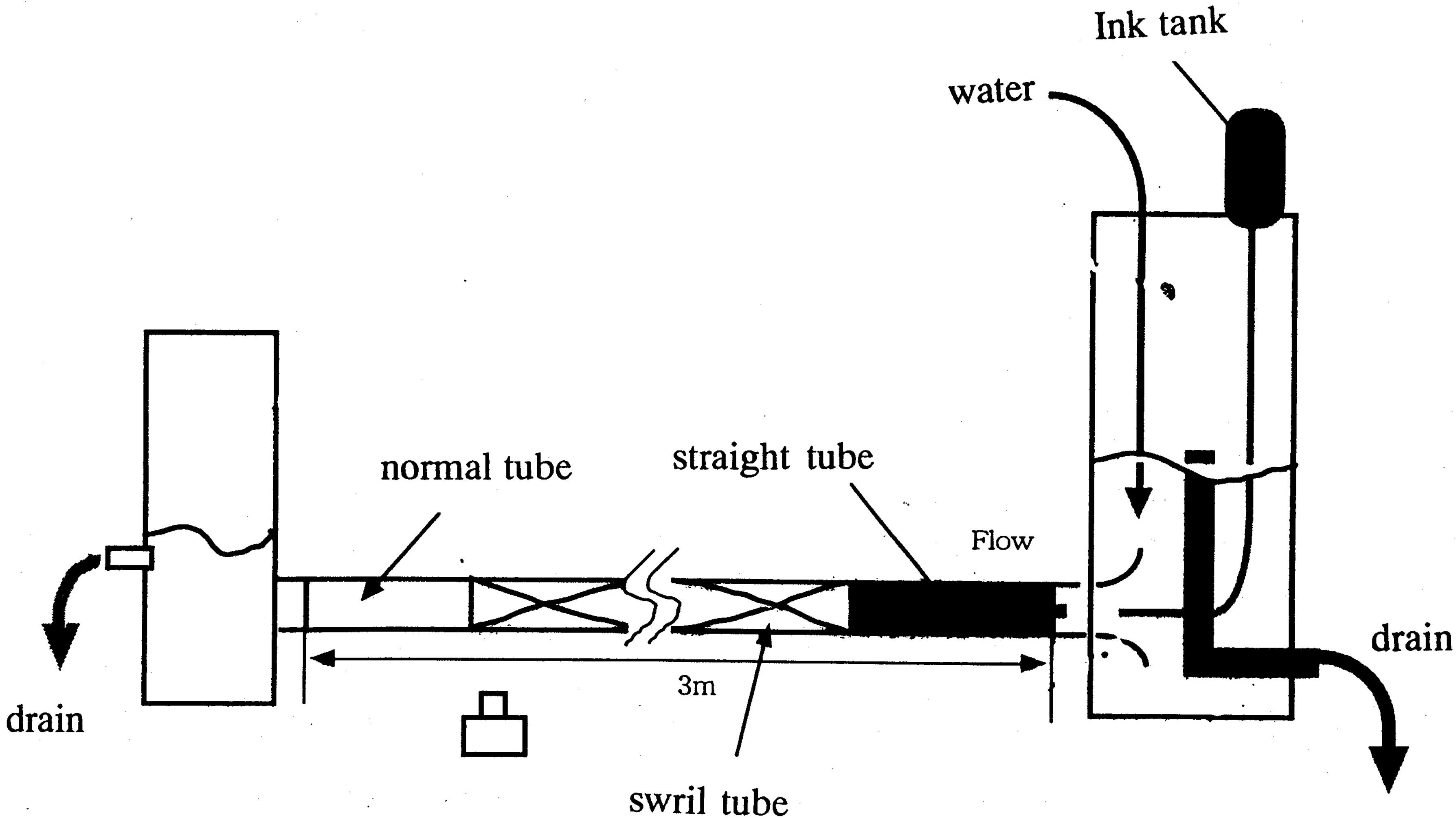
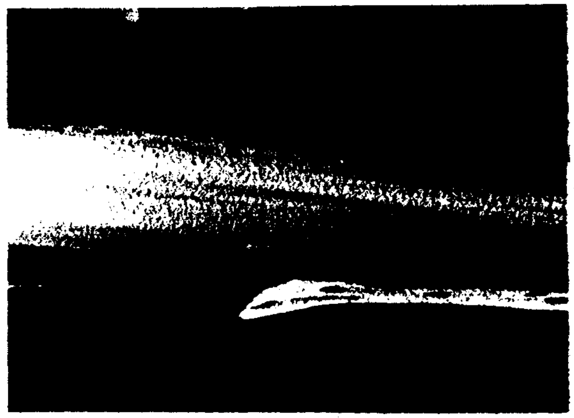


Fig.5: Distribution of critical Re number

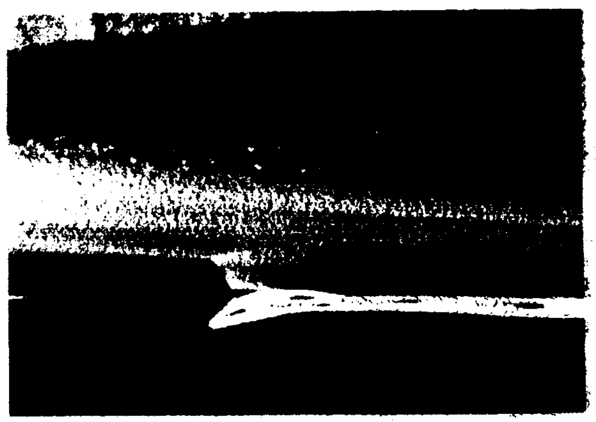
(Pr=3、Gr=2×10⁴)



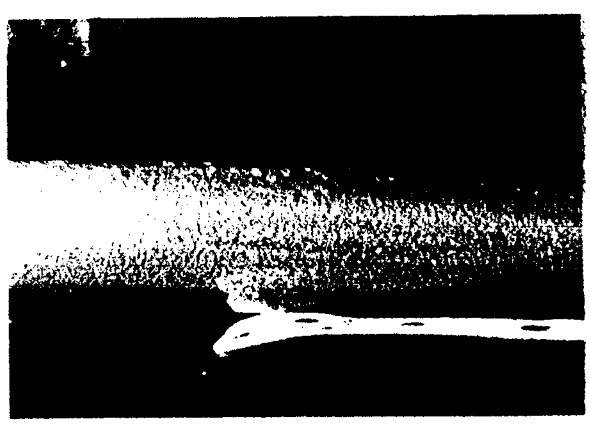
Experimental system



(a) Re_{Sw}=1638

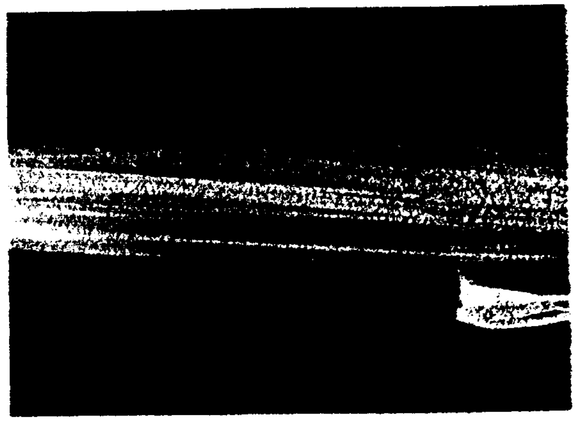


(b) Re_{Sw}=1693

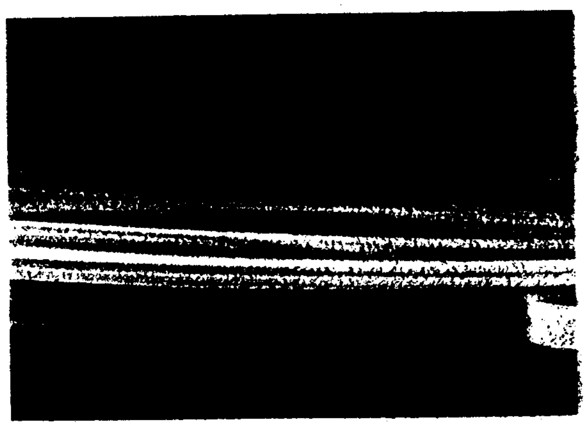


(c) Re_{Sw}=1771

Figure γ=8.9



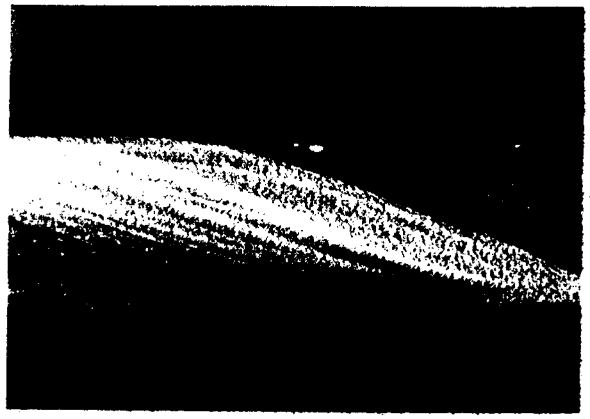
(a) $Re_{Sw}=1188$



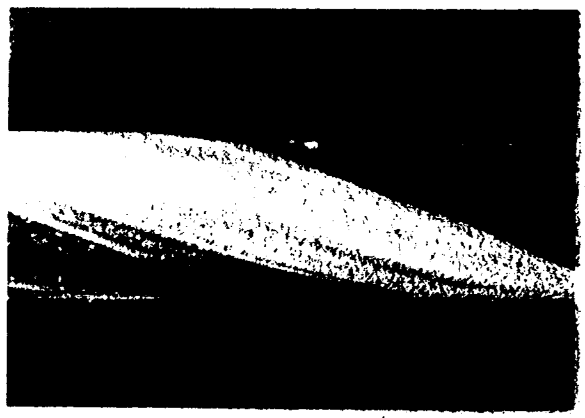
(b) $Re_{Sw}=1344$

(c) $Re_{Sw}=1550$

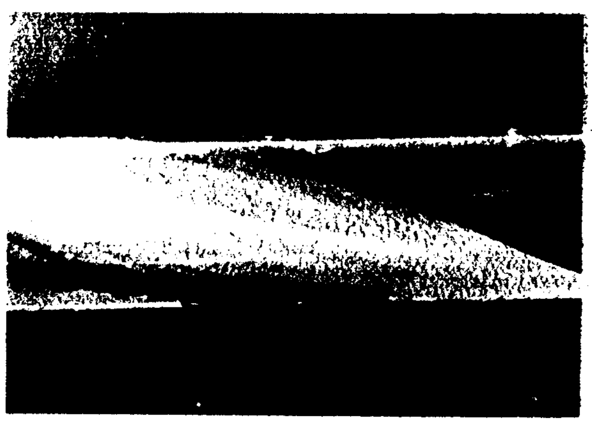
Figure $\gamma=8.9$



(a) Re_{Sw}=600

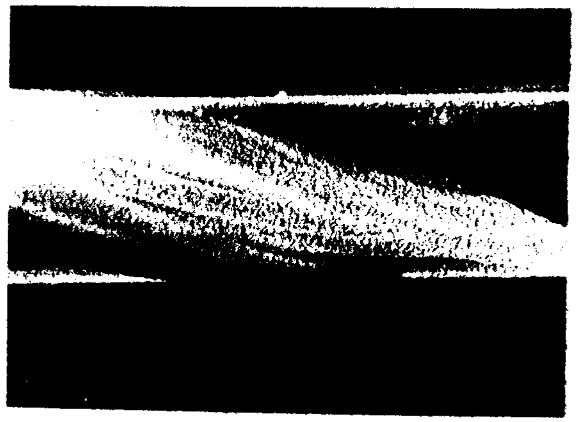


(b) Re_{Sw}=713

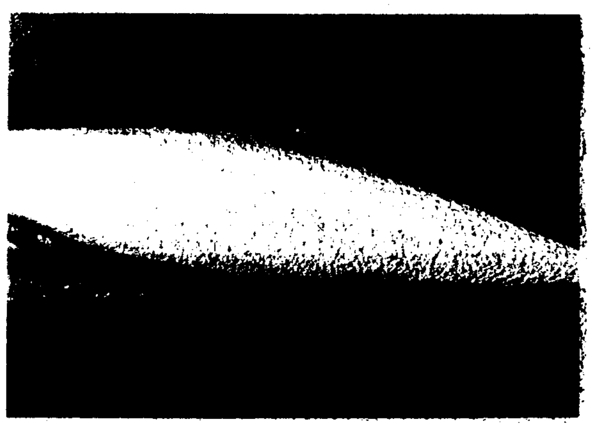


(c) Re_{Sw}=738

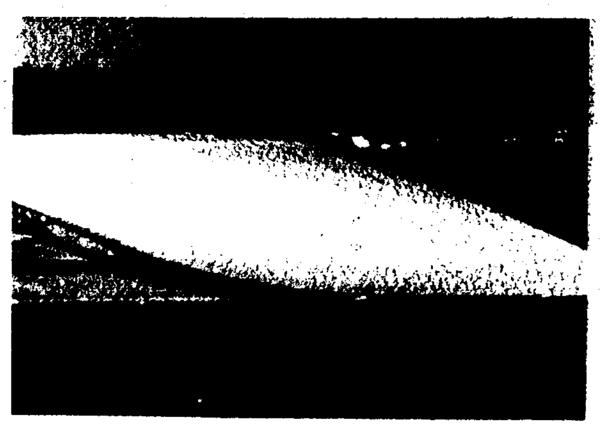
Figure γ=3



(a) Re_{Sw}=837



(b) Re_{Sw}=872



(c)) Re_{Sw}=1168

Figure γ=3

作動流体 FliBe

(Re=1500　Pr=35.6　y=5)

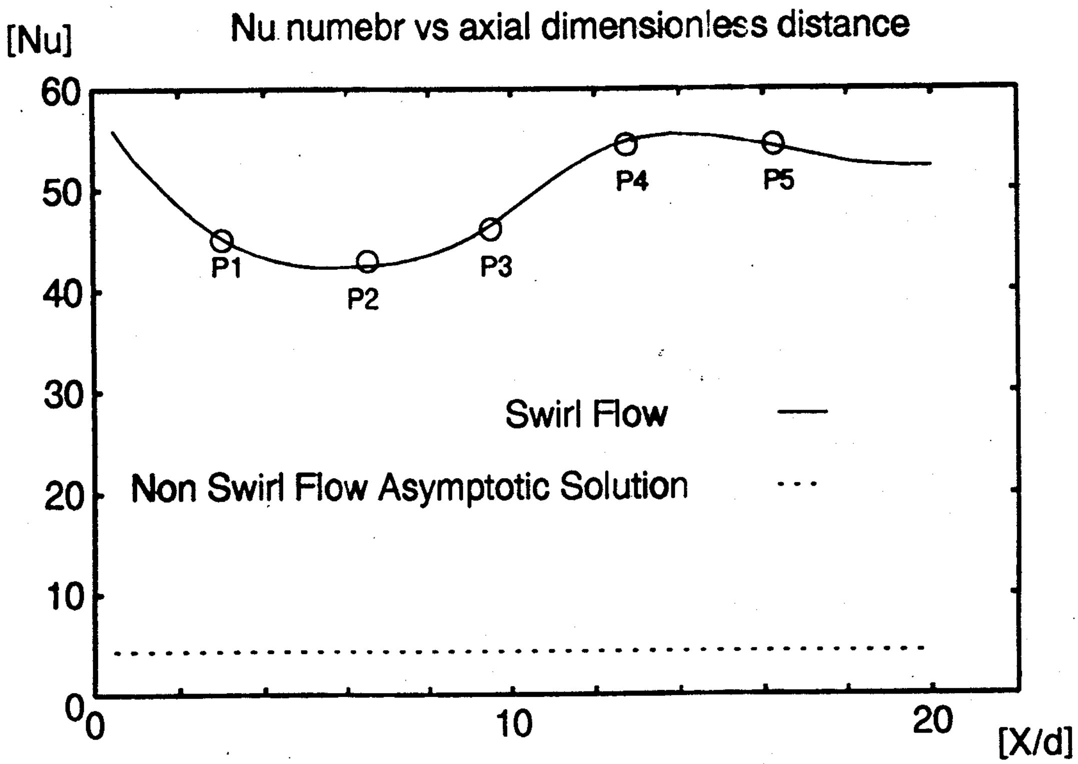


図 1: FLiBe における管軸方向 Nu 遷移

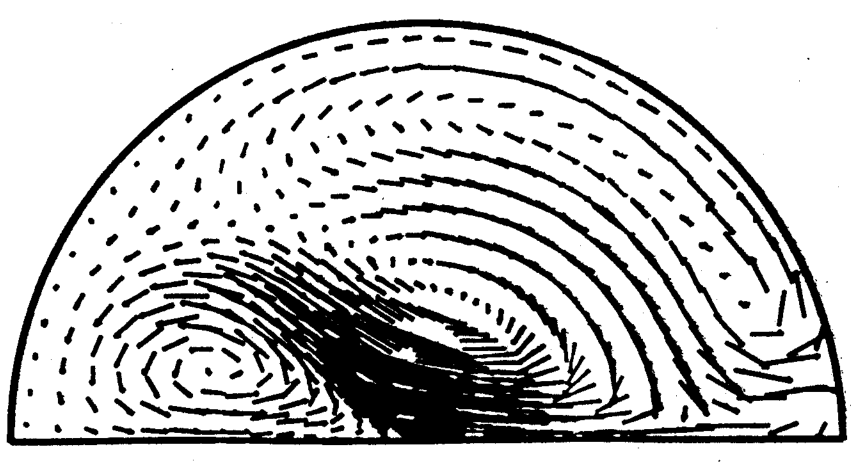


図 2: 断面速度分布 P1

SWIRL DESIGN PROGRESS

DESIGN HIGHLIGTHS OF SWIRL CONCEPT FOR ST CONFINEMENT CONFIGURATION

ST Confinement Configuration Design and Preliminary Swirl Concept Operating Parameters.

ST (I) : Base Design

ST(II) : 50 % Lower Inboard Vertical Velocity

ST(III) : Base Design with 10 MW/m^2 Neutron Wall Loading.

*Required pumping power for swirl concept in ST confinement configuration for a outboard liquid wall thickness of .3 m is < 30 MW.

* Operating fluid may be recycled 5 times for a average higher outlet temperature (~50 C higher) if there is a factor of two increase in the surface heat transfer coefficient.

	ST (I)	ST (II)	ST (III)
Major Toroidal Radius (m)	2.896	2.896	2.896
Minor Radius (m)	1.81	1.81	1.81
Plasma Aspect Ratio	1.6	1.6	1.6
Plasma Vertical Elongation	3.69	3.69	3.69
Outboard Fluid Azimuthal Inlet Velocity (m/s)	11.0	11.0	11.0
Outboard Fluid Vertical Inlet Velocity (m/s)	4.5	4.5	4.5
Outboard Average Coolant Velocity (m/s)	10.0	10.0	10.0
Outboard Maximum Flow Area (m^2)	9.89	9.89	9.89
Av. Outboard Liquid Wall Thickness (m)	.3	.3	.3
Outboard Volumetric Flow Rate (m^3/s)	98.9	98.9	98.9
Outboard Mass Flow Rate (kg/s)	$1.94\ 10^5$	$1.94\ 10^5$	$1.94\ 10^5$
Inboard Fluid Vertical Inlet Velocity (m/s)	15.0	10.0	10.0
Inboard Maximum Flow Area (m^2)	4.4	4.41	4.41
Av. Inboard Liquid Wall Thickness (m)	.5	.5	.5
Inboard Volumetric Flow Rate (m^2/s)	66.1	44.1	44.1
Inboard Mass Flow Rate (kg/s)	$1.29\ 10^5$	$8.65\ 10^4$	$8.65\ 10^4$
Fusion Power (MW)	3845.0	3845.0	4372.
Average Wall Load (MW/m^2)	8.8	8.8	10.
Total Pumping Power (MW)	27.3	17.14	17.14
Average Temperature Rise (K)	5.17	8.61	9.38