



# Three-dimensional flow analysis of a thermosetting compound in a motor stator

■ J.Saeki, "Three-Dimensional Flow Analysis of a thermosetting Compound in a Motor Stator", *SEIKEI KAKOU*, **20**,750-754 (2008)

# Problems of resin filling in motors and aim of this study

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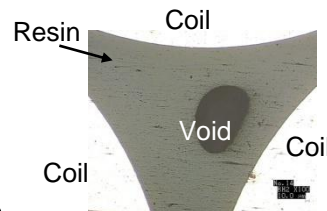
**Trend**  
**High power**  
**Miniaturization**

■ Coil-occupied space becomes larger  
↓  
Coil-gap space becomes smaller

■ High heat generation  
↓  
Requirement for high heat dissipative materials and structure

**Shortage of resin filling**

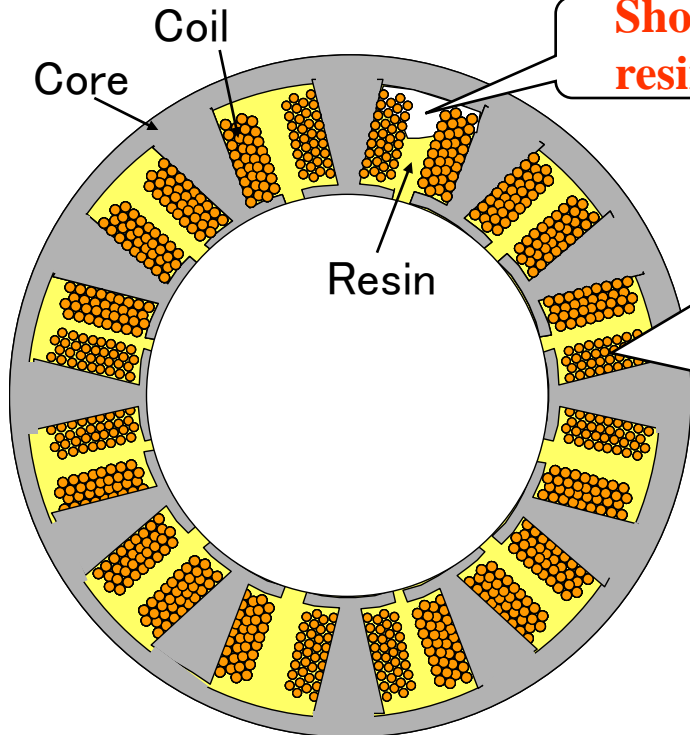
**Void formation**



**Coil fixing and electrical insulation becomes difficult**

**Aim of this study**

- Prediction of resin filling behavior
- Determining mechanisms of ocureing defects
- Process optimization



Cross-sectional view of a motor stator

# A method of analyzing filling dynamics



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## Viscosity equation model (*Saeki's model- I*)

$$\eta = \eta_0(T) \left( \frac{1+t/t_0(T)}{1-t/t_0(T)} \right)^{C(T)}$$

$$\eta_0 = a \exp(b/T), \quad t_0 = d \exp(e/T),$$

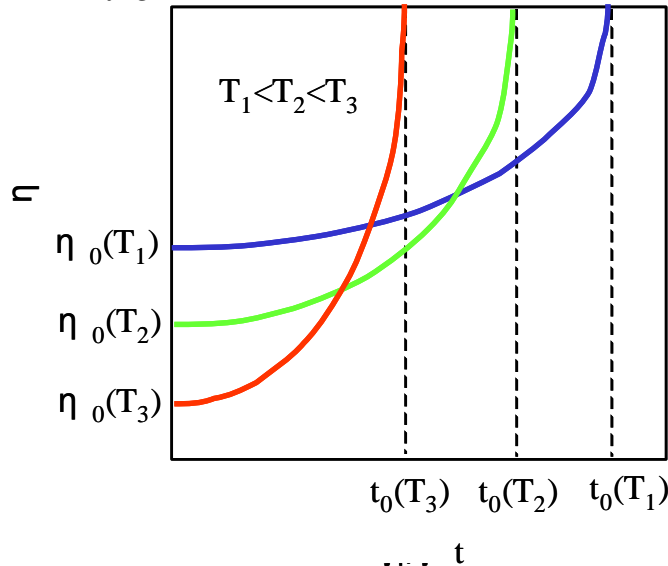
$$C = f/T - g$$

$\eta$ : viscosity,  $t$ : time,  $T$ : temperature,

$\eta_0$ : initial viscosity,  $t_0$ : gel time,

$C$ : coefficient to define  $\eta$ - $t$  profiles,

$a, b, d, e, f, g$ : coefficients inherent in each resin



Determining viscosity parameters

Developing a method for calculating  
complicated coil gaps

Customizing FLOW-3D®

3-D flow analysis in  
motors

Time

# Parameters of the thermosetting molding compound and verification

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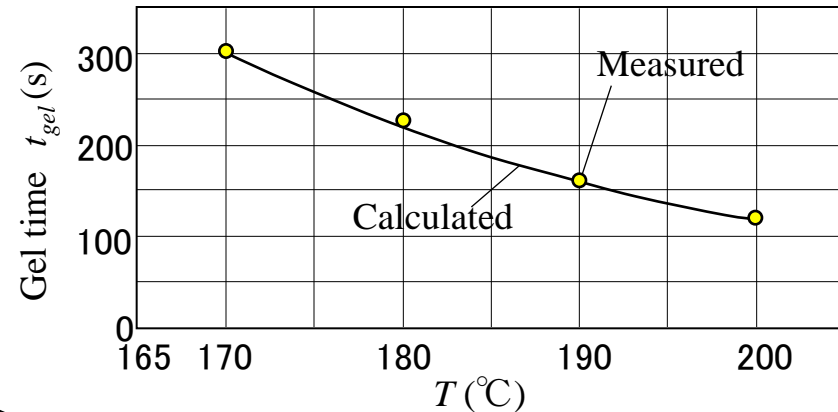


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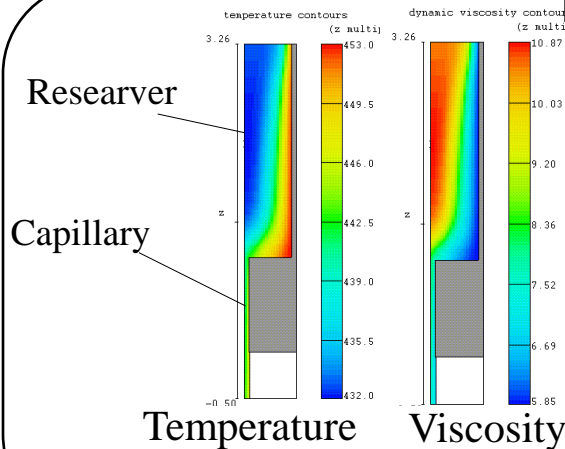
## Parameters

Parameters in the viscosity model	$a(\text{Pa} \cdot \text{s})$	1.35E-8
	$b(\text{K})$	8707
	$d(\text{s})$	1.6E-4
	$e(\text{K})$	6400
	$f(\text{K})$	935.4
	$g(-)$	0.265
Density ( $\text{kg}/\text{m}^3$ )	3100	
Specific heat ( $\text{J}/(\text{kg} \cdot \text{K})$ )	800	
Thermal conductivity ( $\text{W}/(\text{m} \cdot \text{K})$ )	5.0	

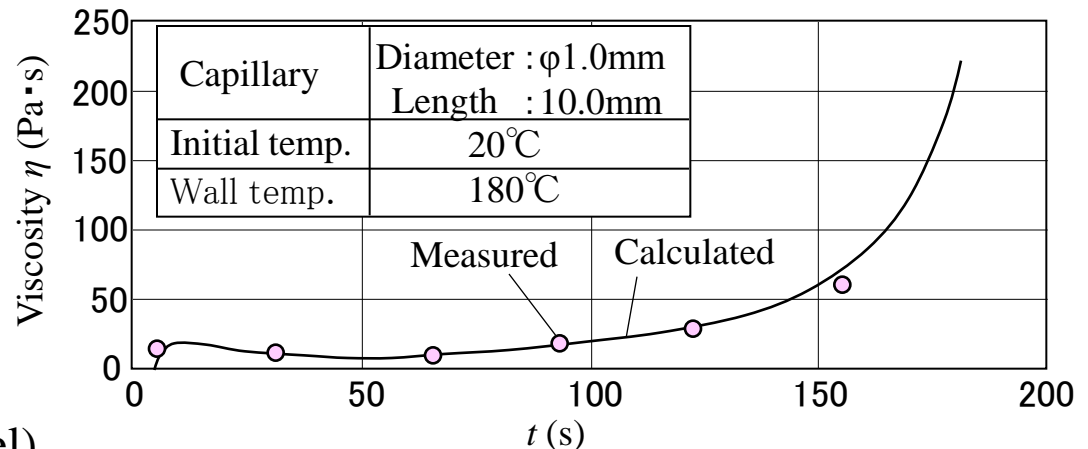
## Comparison of gel time



## Comparison of viscosity changes



Analysis(Symmetrical model)

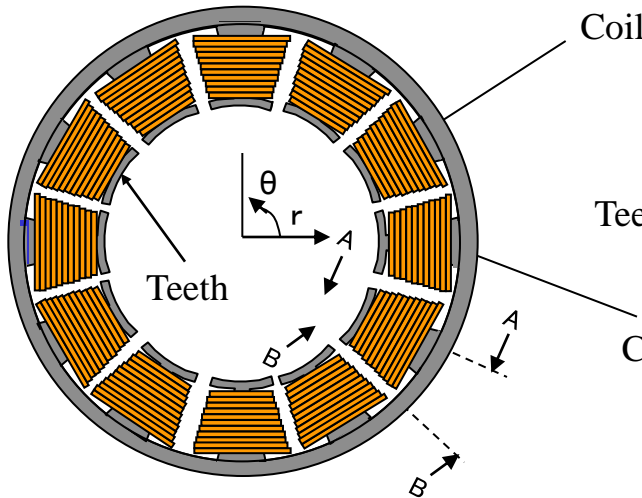


Capillary	Diameter : $\phi 1.0\text{mm}$ Length : $10.0\text{mm}$
Initial temp.	20°C
Wall temp.	180°C

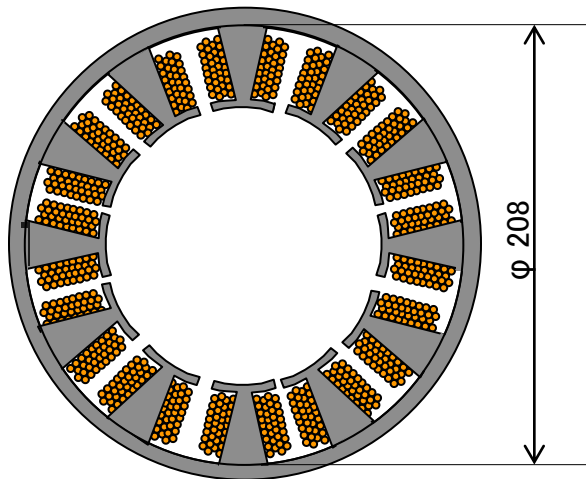
# Schematic diagram of a motor stator



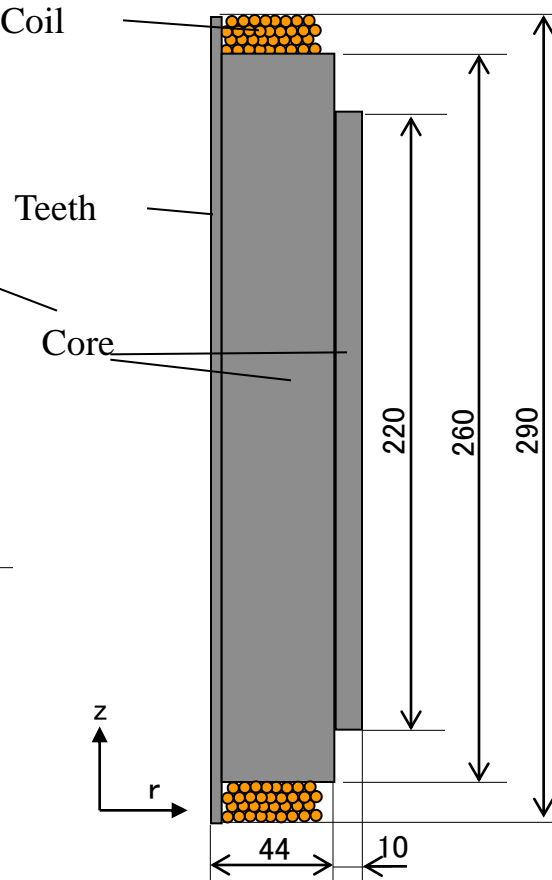
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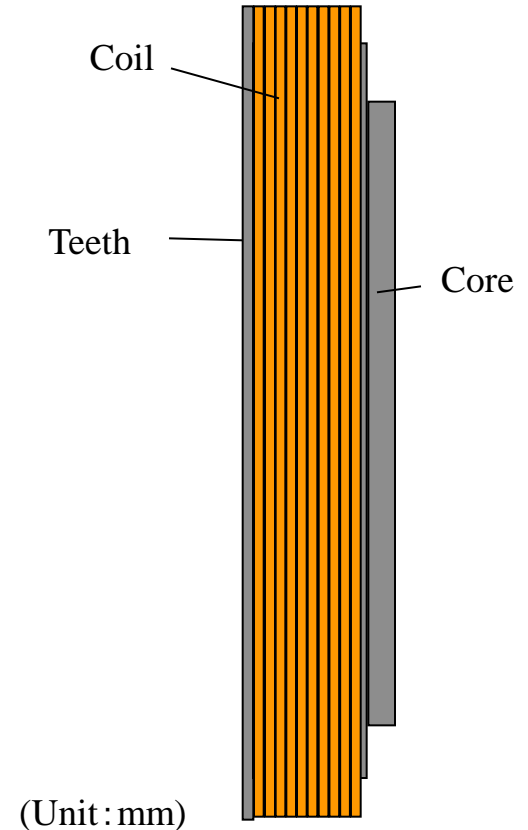
(a) Plan view



(b) Cross-sectional view of r-θ plane



(c) Cross-sectional view along A-A direction

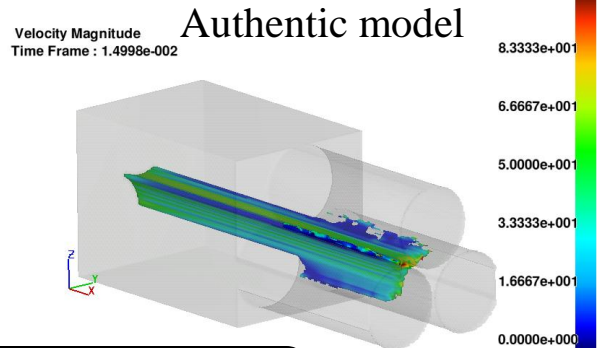


(d) Cross-sectional view along B-B direction

■ Similar size to HEV(Hybrid Electric Vehicle) motor

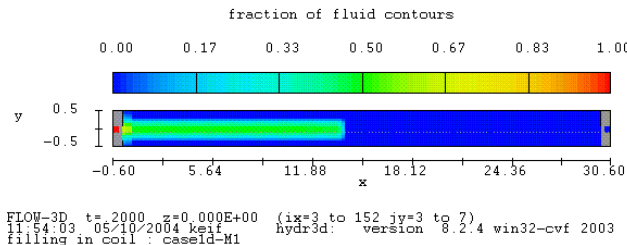
# Preliminary study for modeling of coils

## Simulation using three-stacked coils (L=300mm)



**This model is not practical**

## Porous-media model using Flow-3D



Elements : 3750  
Calculation time: 3 minutes

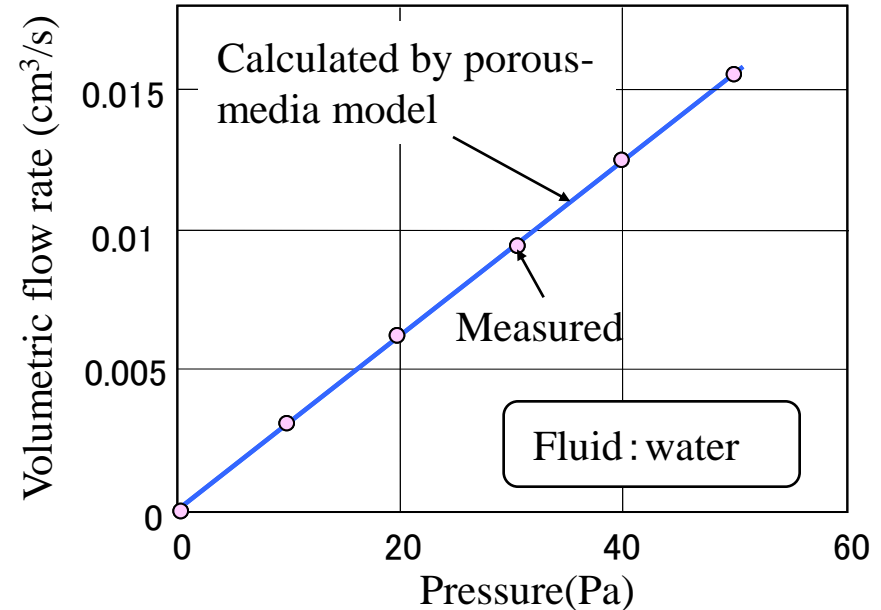
**Possible to calculate whole coils in the stator**



Customer Satisfaction  
by Computer Simulation  
& Computer Simulation

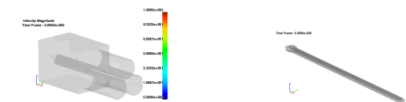
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## Verification



## Adoption of porous-media model for calculating coil portion

- ◆ Calculation time : 1/2000 of authentic model
- ◆ Accurate calculation is possible



# A method of calculating coil portions



Computer Simulation  
by Computer Simulation  
& Computer Simulation

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## Modification of porous-media model

### Conventional D'Arcy rule equation model

$$\Delta P = K \cdot u \cdot \rho \cdot L$$

$\Delta P$ : pressure drop,

$K$ : drag coefficient,

$u$ : velocity,  $\rho$ : density,  $L$ : flow length

### Modified equation model

$$\Delta P = \eta \cdot \beta \cdot u \cdot \rho \cdot L$$

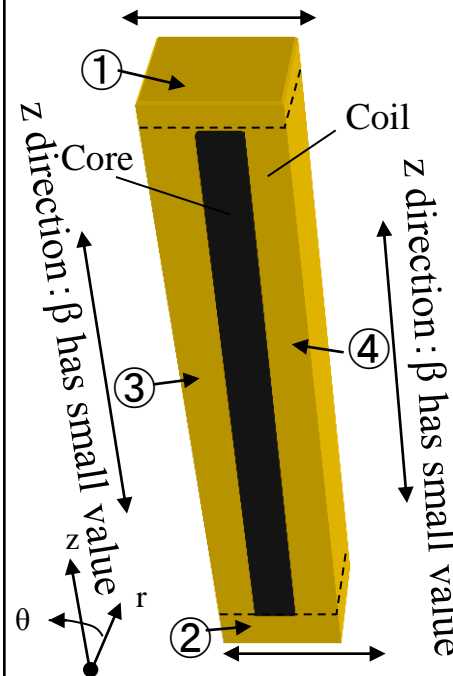
Calculation using thermoset viscosity model

$\eta$ : viscosity,

$\beta$ : shape resistance of cross section

## Modeling of the coils

$\theta$  direction:  $\beta$  has small value



Values of  $\beta$

$\beta((\text{Pa} \cdot \text{s}^2)^{-1})$			
Zone		①,②	③,④
Direction	r	1.0E7	1.0E7
	$\theta$	1.0E6	1.0E7
	z	1.0E7	1.0E6

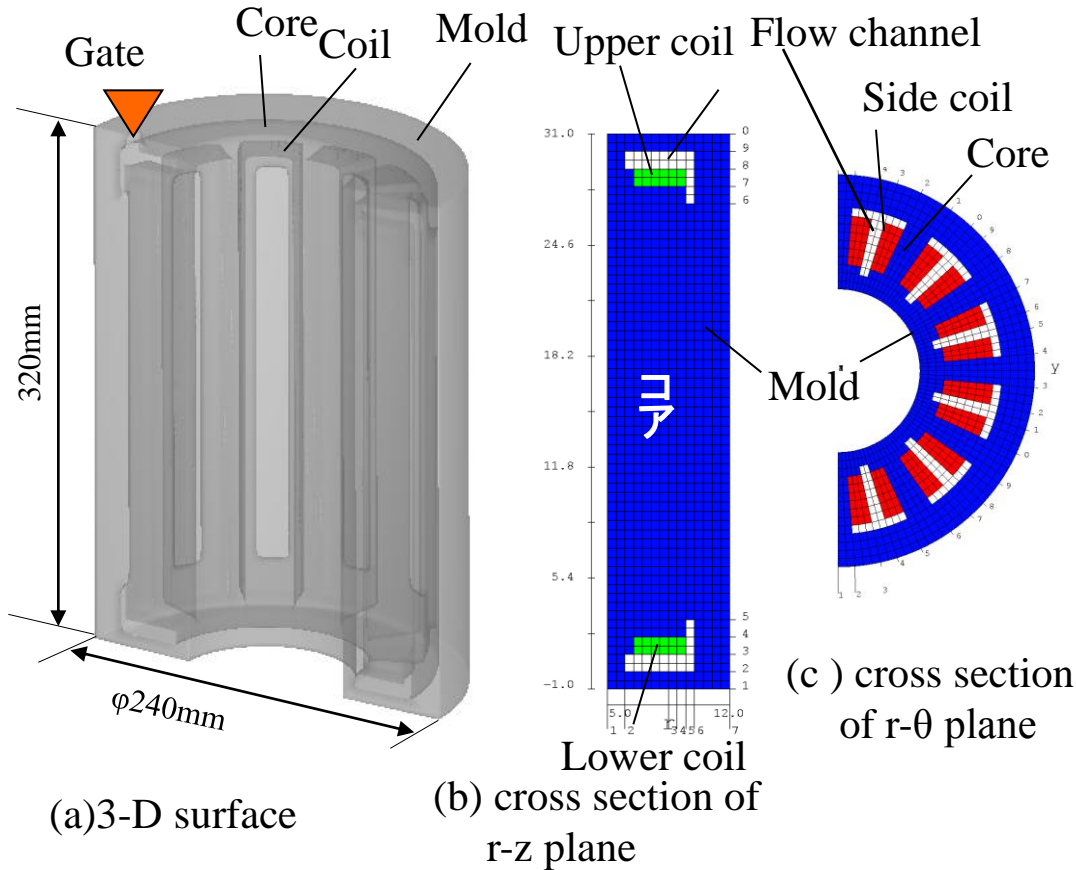
$\theta$  direction:  $\beta$  has small value

# Modeling of the stator and input data



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## Modeling



Elements:  $15 \times 70 \times 60 = 63,000$  (Symmetrical half model)

## Input data

Resin parameters	Fixed values
Initial temperature of resin ( $^{\circ}\text{C}$ )	75
Mold temperature( $^{\circ}\text{C}$ )	180
Filling time(s)	30
Preset pressure(MPa)	9.8

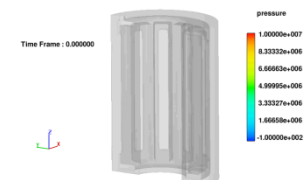
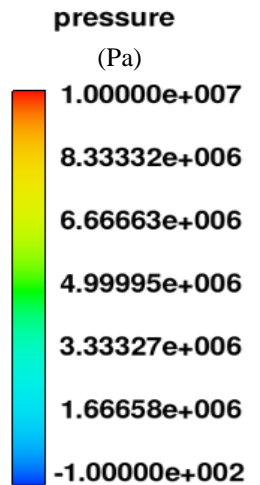
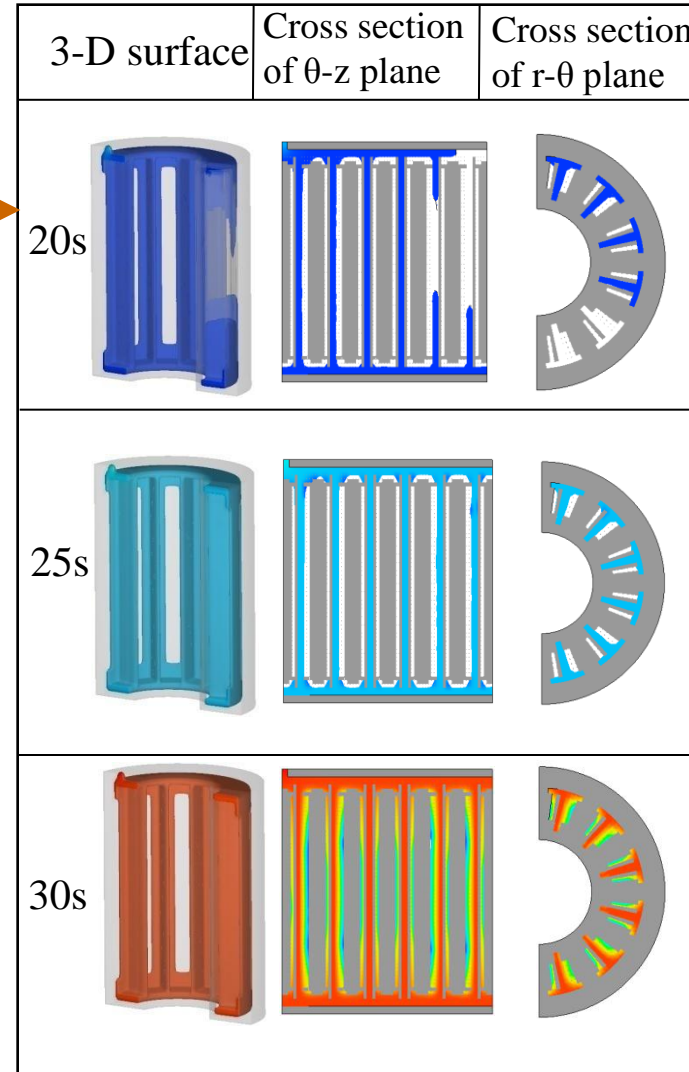
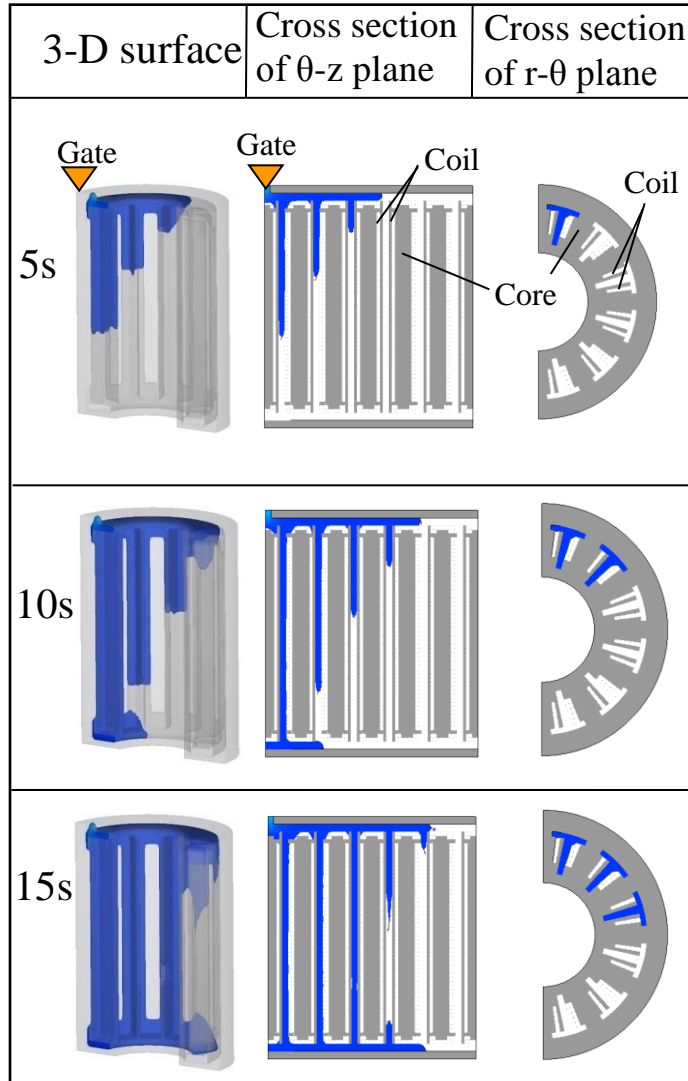


# Calculated results of filling behavior and pressure distribution with time lapsing

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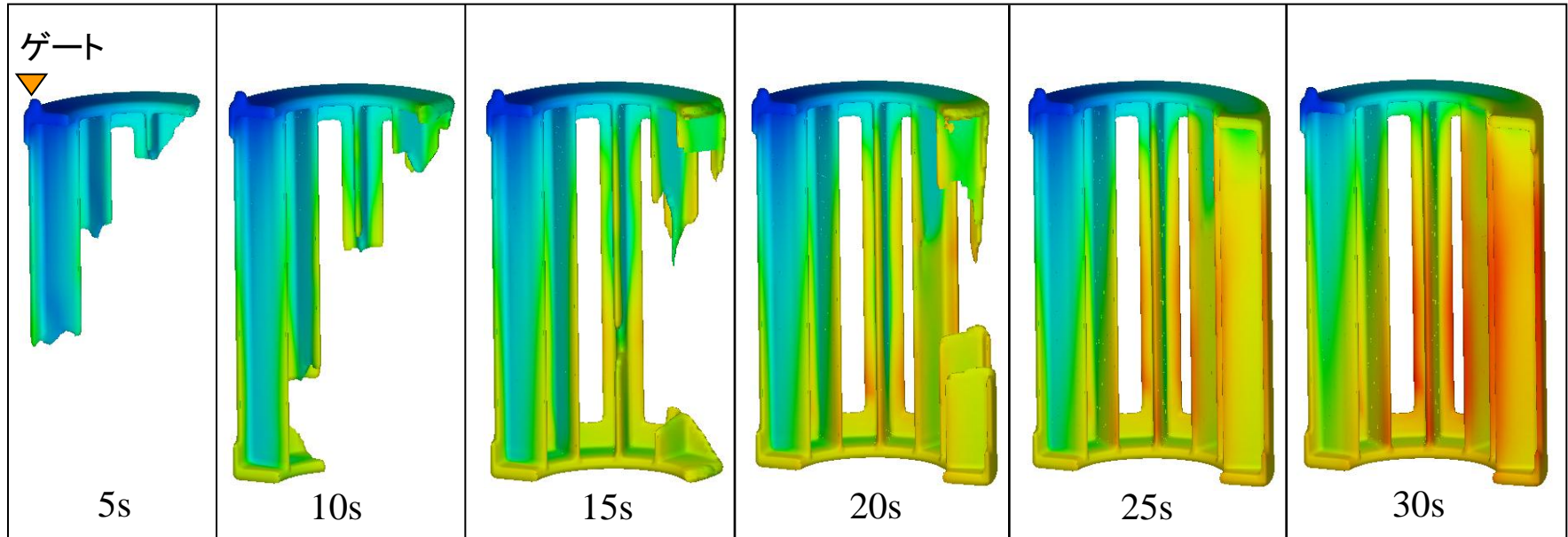


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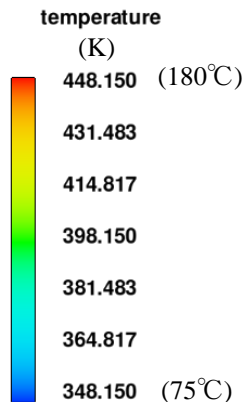


# Calculated results of filling behavior and temperature distribution with time lapsing

10

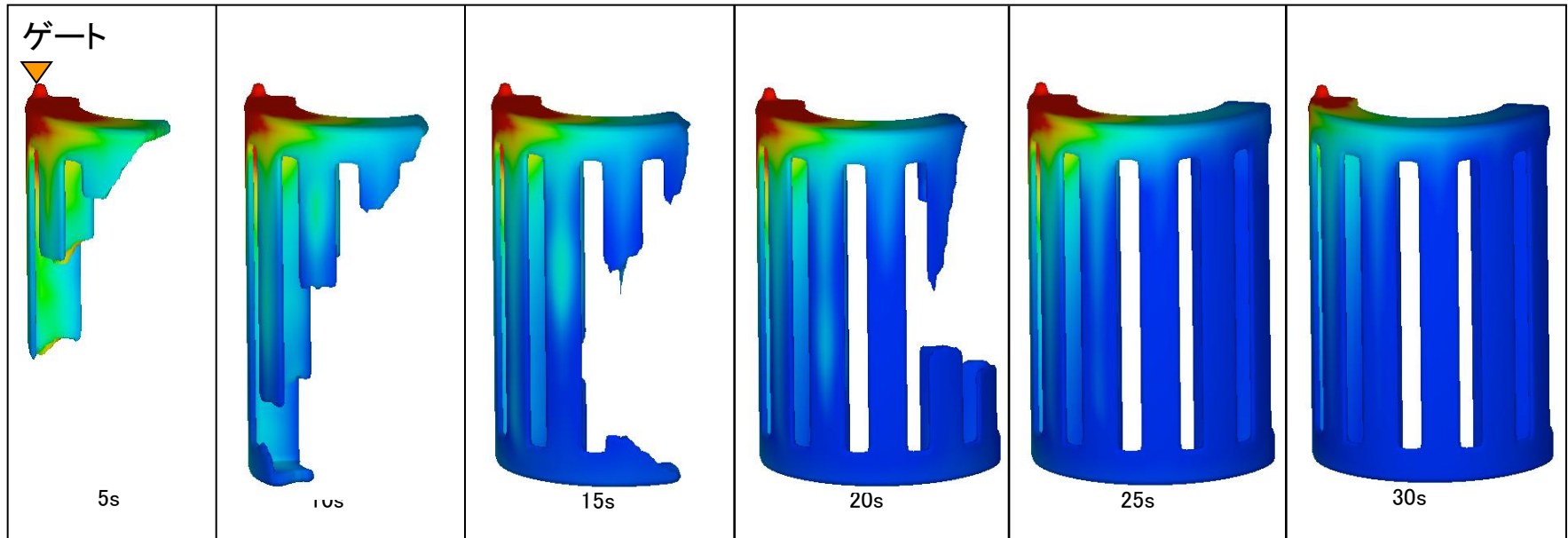


3-D surface

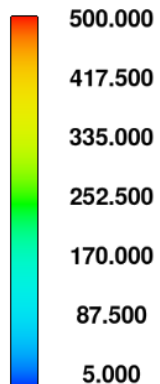


# Calculated results of filling behavior and viscosity distribution with time lapsing

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Viscosity(Pa・s)



3-D surface

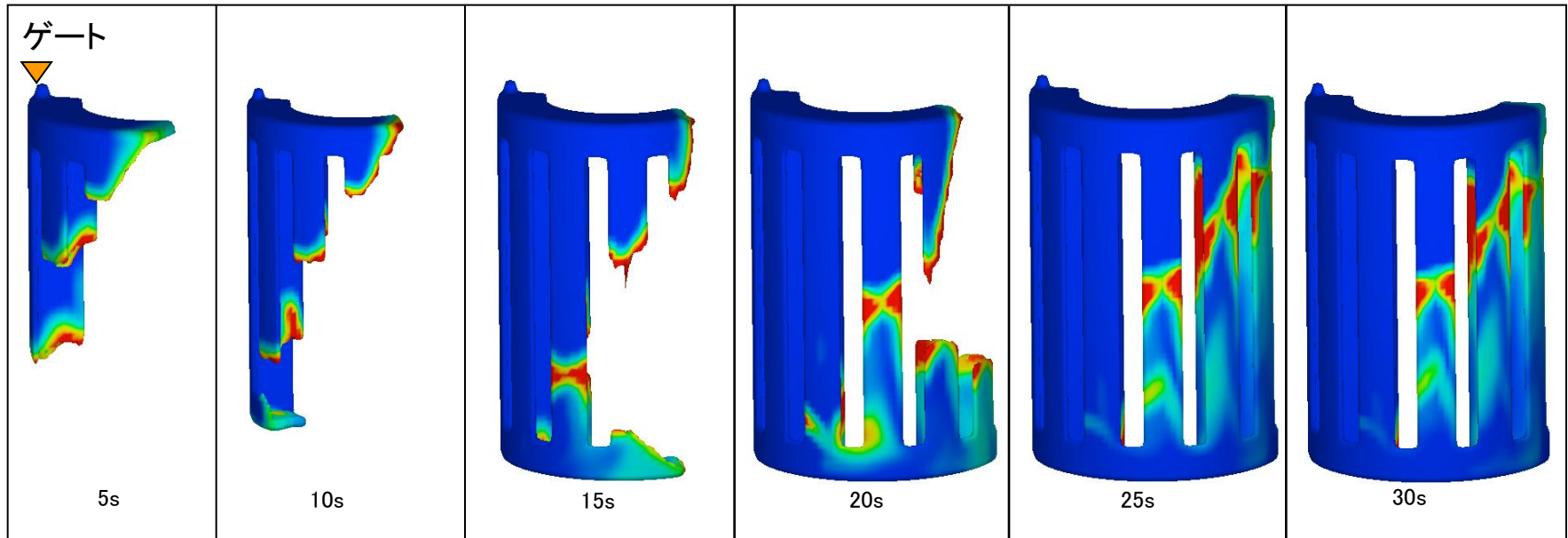
Time Frame: 0.000000



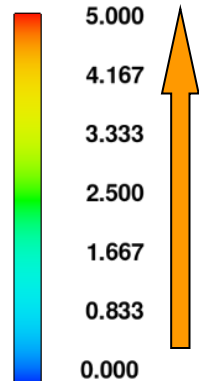
# Calculated results of filling behavior and weld index distribution with time lapsing

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Weld index



Index of contacting time with air

3-D surface



Calculation time : 4h

(In case of authentic model, more than 300 days will be required)