DEVELOPMENT OF MITSUBISHI HIGH THERMAL PERFORMANCE GRID 2 - OVERVIEW OF THE DEVELOPMENT AND DNB TEST RESULTS -

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ABSTRACT

Spacer grid plays fundamental roll in thermal performance of PWR fuel assembly. Grid spacer with higher thermal performance gives greater DNB margin for the core. Mitsubishi has developed a prototype Zircaloy grid with higher thermal performance. In this paper, process of the development and DNB test results of the grid is presented.

To achieve a goal to design grid with higher DNB performance, CFD and Freon DNB test are employed in the development. It is also concerned that the grid should be hydraulically compatible to existing grid. CFD is used in examining mixing capability and pressure drop for early stage of the development. Freon DNB test is used for preliminary checking of DNB performance for several design of the grids.

After the final design is fixed, DNB test has been carried out at a high pressure / high temperature water test loop to verify the DNB performance. Also, hydraulic test has been done in a water test loop. The test results show that the grid has higher DNB performance and lower pressure loss coefficient compared with existing grid. It is also concluded that a combination of CFD and Freon DNB testing is successful tool for designing and development of grid.

SUMMARY

Mitsubishi Heavy Industries have been developing a high performance grid spacer for PWR. In this paper it is presented that process of the development toward smaller pressure drop and high CHF characteristics comparing current Zircaloy grid spacer as well as high reliability and high performance in seismic performance.

OBJECTIVE OF THE DEVELOPMENT

Mainly Inconnel grid spacer has been used in Japanese PWR core. However, gradually Zircaloy grid spacer that has better neutron economics, etc, is going to be used more widely there. Mitsubishi has already experienced more than two cycles of burn-ups in Japanese PWR core. Recently it is expecting that more thermal margin in the core toward future up-rating of the PWR plant. To achieve the expectation, the high performance grid spacer has been developed.

Introduction of high thermal performance grid spacer to the core gives more thermal margin, then increase safety revel of the core. Also, characteristic of lower pressure drop gives less DNB penalty in mixed core with current Inconnel grid spacer that has usually has lower pressure drops than Zircaloy grid spacer. In reload core the high thermal performance grid spacer gives greater thermal margin to core operation. Also, in the future when the current DNB correlation is modified to agree with the performance of the grid spacer, thermal performance of the core becomes better to have more thermal margin in licensing calculations, such as higher minimum DNBR values in the events where DNBR is concerned. The up-rating of PWR core would be achievable more easily when the additional thermal margin is gained by introduction of the high performance fuel.

FEATURES OF THE GRID SPACER

Mitsubishi has developed two high thermal performance prototype grid spacers. Both of the grids have same design of strap. Difference of the two grids is on mixing vane design. One of the designs has ordinary type of mixing vane. Figure 1 shows the grid. Another design of the grid has newly designed and developed "Crossover type" vane. The crossover vane is shown in figure 2. The feature of the crossover vane is described in next section. The designs of grid are named as MHP1 and MHP2 respectively. MHP1 employs ordinary type of mixing vane and MHP2 employs the crossover type of mixing vane.

Both types of Mitsubishi High Performance grids have been developed with following concepts.

(1) higher DNB performance comparing with current Inconnel and Zircaloy grid

(2) lower pressure drop comparing with current Zircaloy grid

(3) high seismic performance as same as current Inconnel grid

(4) high reliability in operating core with I-type scratch-less rod loading mechanism

DETAILS OF THE GRID

Mixing vane

Mixing vane has been widely used in PWR grid spacer to improve Critical heat flux of its fuel. One type of the High Performance grid has ordinary type of mixing vane that is slightly larger than previous Inconnel grid. Another type of the grid has the crossover vane.

Ordinary design of mixing vane is leaned toward the rod paralleling to grid strap. Lateral flow created by the ordinary vane hits directly rod surface, then it would lose its momentum. The crossover vane is designed to create lateral flow to the direction that is closer to tangent line of rod surface. The crossover vane leaned to direction that cross over strap to the adjacent rod. The lateral flow created by the crossover vane would not hit directly rod surface, then it would not lose its momentum compared with ordinary type of vane. Overall, the crossover vane is designed to optimized lateral flow direction created by the vane. As a result, the vane has lower pressure drop with keeping high DNB performance. Figure 2 shows a bird view of the crossover vane.

DNB performance

Current type of Mitsubishi Zircaloy grid has the performance that matches MIRC-1 DNB[1] correlation which was developed with DNB test data taken at Columbia University. Both of the High Performance grids have greater DNB performance than the current grid. The performance is also confirmed by DNB tests conducted at a test loop in Columbia University. The test results is described in later section.

Pressure drop

A hydraulic test is conducted to measure pressure drop of the grids as well as current type of grid for comparison at a test loop in Nuclear Development Corporation in Tokai, Japan. The test results shows that pressure drops of the high performance grids are lower than current type of Zircaloy grid. It is evaluated that pressure loss coefficient of the new grid will be around 10% lower than current Zircaloy grid.

Scratch-less rod loading mechanism

Mitsubishi I-type grid has a feature that the scratch-less rod loading mechanism. The mechanism allows no–scratch damage on fuel rod surface during fuel assembling. The high performance grid has taken over the feature with its I-type spring.

Seismic performance

It is generally difficult in the grid design to achieve raising or maintaining of the seismic strength and reducing of the pressure drop at a same time. In this development, it is contrived that the grid has the equivalent seismic performance and the lower pressure drop compared with the current Zircaloy grid. The performance has been confirmed through 5x5-model tests.

PROCEDURE OF THE DEVELOPMENT

CFD, Freon DNB testing and hydraulic pressure drop testing are performed in the development. Also, in the last part of the program, DNB tests were conducted at test loop in Columbia University. The hydraulic and DNB test results show that procedure of the development is successful to achieve the target of high DNB performance and low pressure drop. On the course of the development many types of prototype grid have been considered, then analyzed and tested using CFD, Freon DNB test and hydraulic test. Figure 1 shows some cases of prototype grids in later part of the program with application of CFD, testing to those cases.

Application of CFD

Mitsubishi High Performance grids have been developed using CFD analysis to estimate pressure drop, mixing characteristics and crossflow distribution. CFD in single-phase flow condition is used in this development program. The CFD is effective tool to estimate its pressure drops before flow test is conducted. Even though DNB is two phase flow phenomena, flow estimated by CFD under the single-phase flow condition is very informative in design process to a certain extent before DNB test was conducted to confirm its characteristics. The CFD technique has been verified by comparing flow test results that is crossflow distribution downstream of mixing vane grid.

To verify the CFD crossflow velocity is measured by specially designed Laser Doppler Velocimeter (LDV). The probe of the LDV is installed in one of the rod in test rod bundle. Detail of the LDV system and verification is described in reference[2].

The design work is proceeded based on an assumption that mixing characteristics in single-phase flow is correlated to DNB characteristics.

Figure 3 shows analytical domain of CFD. Figure 4 shows an example of results of mixing characteristics of the high performance grid. The CFD is modeling a 5x5 rod bundle that is same as water DNB test. Axial length of the model is 460mm that is one grid span. Heat output of the peripheral rods is 15% lower than interior rods corresponding lateral power distribution of water DNB test bundle. Peak temperature of coolant is observed in a calculation cell on interior rod surface of the outlet. Mixing characteristics is evaluated by comparing peak temperature in the cross-section of the outlet among CFD cases. Grid design affects the peak temperature and its location. Figure 4 shows peak temperature and its location for the high performance grid. Table 1 shows specification of the major prototype grid in last part of the development program and their mixing characteristics evaluated by CFD. The mixing characteristics are presented as difference of peak temperature and average temperature of the outlet cross-section (DT).

Freon DNB test

In the high quality region single-phase CFD is not sufficient to estimate flow characteristics. To confirm and study the DNB characteristic of the selected design of the prototype grid, Freon DNB test is conducted at a test loop in Mitsubishi Takasago Laboratory. Figure 5 to 7 show the Freon DNB test loop, test section and test bundle. 3x3 rod bundle is employed in the test. Axial heated length is 1.5m and the power distribution is uniform. R-123 is used as coolant. Heat output of peripheral rods is 20% lower than center rod to avoid DNB occurrence in the rods. Freon DNB test is used to compare DNB power of tested grids to reference grid. Test condition is selected to represent corresponding water DNB test condition. Conversion from water to Freon test condition is based on Ahmad's method[3]. The Freon DNB test for each grid is conducted as pressure range from 1.4 to 2.7 MPa, mass velocity range from 140 to 280 $kg/m^2/s$ and local quality from –10 to +20%. The test condition is corresponding in water DNB test as pressure range from 9.8 to 17.2 MPa. Mass velocity range and quality range is considered as same as water test. Figure 8 shows ratio of DNB power for MHP1 and MHP2 grid comparing current type of Zircaloy (Z2) grid. The test condition is precisely controlled during the testing for each data point to achieve targeted condition so that direct power ratio can be used for comparison of corresponding test points with different grid. From this figure both design of the high performance grids, such as MHP1 and MHP2, have about 8% higher DNB power than Z2 grid in average. From the Freon DNB test results it is expected that both grids showed better DNB characteristics than Z2 grid in water DNB test.

Water DNB test

Two designs of prototype High Performance grids, such as MHP1 and MHP2 are selected to conduct water DNB tests.

The water DNB tests are carried out at test loop in Columbia University. The test bundle is axially 3.7 m for heated length with axially cosine power distribution. The axial peak to average power ratio is 1.54. Figure 9 shows lateral power distribution of rods. Figure 10 shows axial location of grids. The peripheral rods have 15% lower power than interior rods to avoid DNB occurrence there.

The test condition is standard condition for PWR fuel that covers test condition of database of MIRC-1 DNB correlation[(4)], such as pressure from 9.8 to 16.6 MPa, mass velocity from 1.4 x 10^3 to 4.7 x 10^3 kg/m^2/s. As a result of test, local quality of data points ranges from about 0 to 40%. The MIRC-1 DNB correlation is developed based on DNB data taken in Columbia University for PWR fuels widely used in licensing calculation in Japanese PWR core to evaluate minimum DNBR.

Figure 12 shows DNB characteristics for MHP1 and MHP2 comparing Z2. The two types of High Performance grids have significant improvement in DNB performance from current Zircaloy grid (Z2). Ratio of measured DNB heat flux (M) and predicted DNB heat flux (P) is calculated for the data points. M/P values of the data points are derived using THINC subchannel code and MIRC-1 DNB correlation to access the characteristics. TDC value of 0.059 is use for MHP1 and MHP2 and 0.030 is used for Z2. Totally 28 test points are selected to compare the test results for those three types of grids. Average value of M/P for MHP1 and MHP2 are around 5% greater than Z2 grid.

CONCLUSION

Mitsubishi has developed two prototype grid spacers, such as MHP1 and MHP2. CFD and Freon DNB test are employed in the development. The grids have greater performance in thermal hydraulic characteristics. MHP1 employs ordinary type of mixing vane and MHP2 has crossover type of the vane. Both grids have higher DNB performance than current Zircaloy grid (Z2). It is also noted that the crossover vane has characteristics of lower pressure drop than ordinary type of vane.

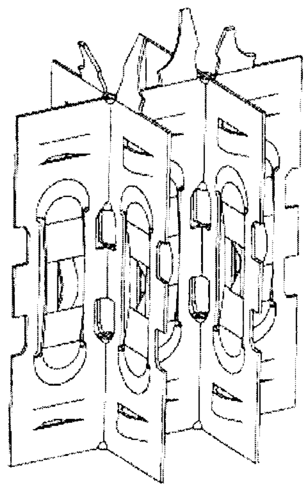

Figure 1 Mitsubishi High Performance Grid (HP1)

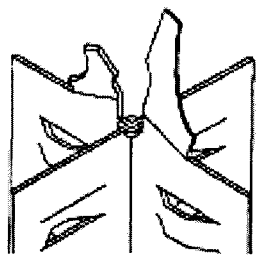

Figure 2 Crossover Mixing Vane

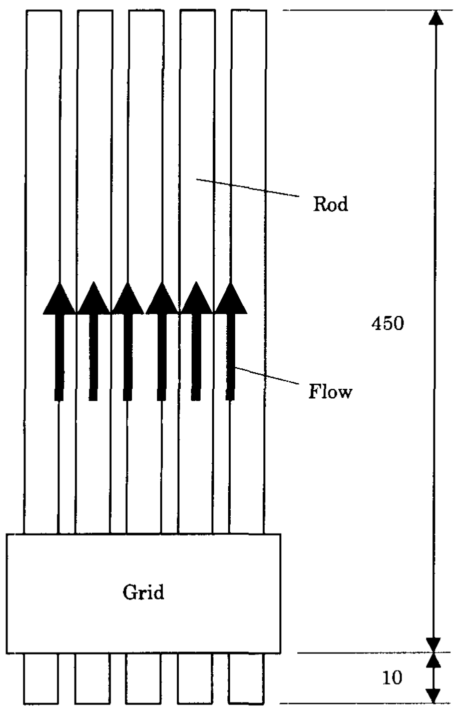

Figure 3 CFD Analytical Domain

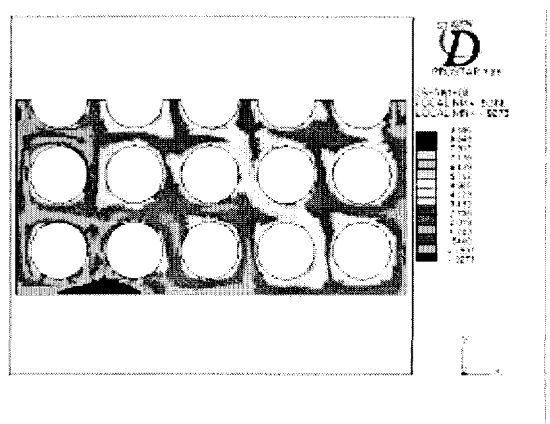

Figure 4 Mixing Characteristics Evaluated by CFD

Grid Type	Strap Thick -ness (mm)	Strap Width (mm)	Spring Type (Notes 1)	Vane Type (Notes 2)	DT (K)	Freon DNB Test	Water DNB Test
Z2 (Current Zircaloy)	0.46	48	Std-I2	Std-S	10.76	Done	Done
P1	0.41	42	Std-IP	Std-A	-	N/A	N/A
MHP1	0.41	43	SL-I	Std-B	9.80	Done	Done
P5K	0.41	43	SL-I	CO-1	10.15	N/A	N/A
P5M	0.41	43	SL-I	CO-2	9.58	N/A	N/A
MHP2	0.41	43	SL-I	CO-3	9.61	Done	Done

Notes 1 Std: Standard type, SL: Streamlined type

Notes 2 Std: Standard type, CO: Crossover type

Table 1 Mixing Characteristics Evaluated by CFD

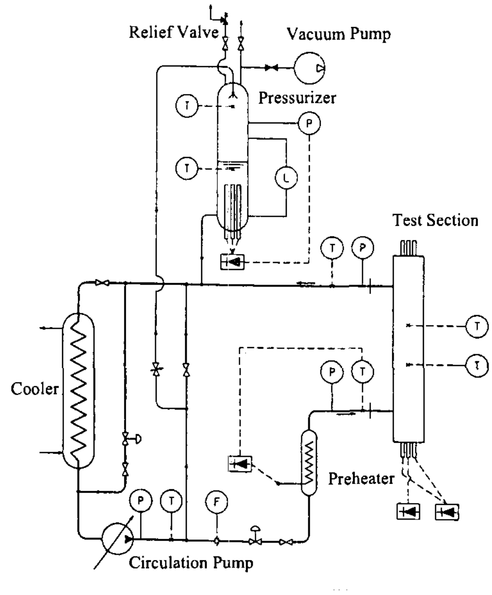

Figure 5 Freon DNB Test Loop

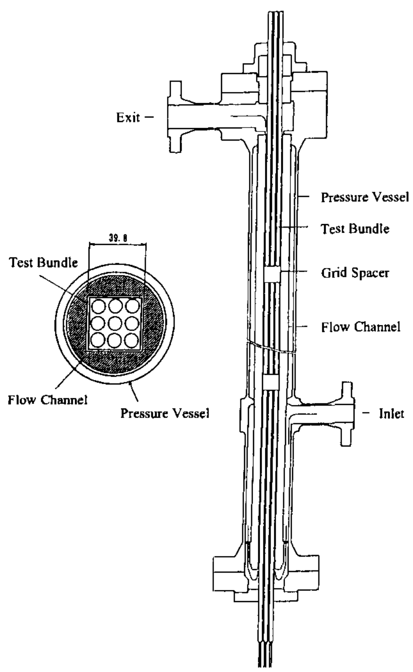

Figure 6 Freon DNB Test Section

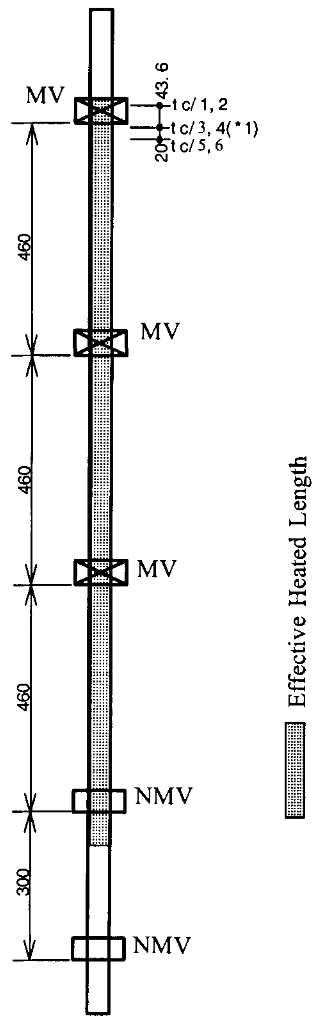

Figure 7 Freon DNB Test Bundle

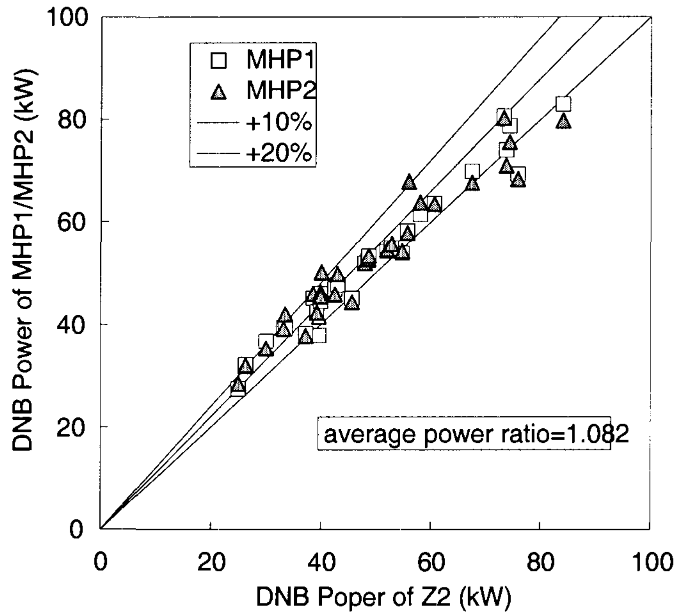

Figure 8 Freon DNB Test Results

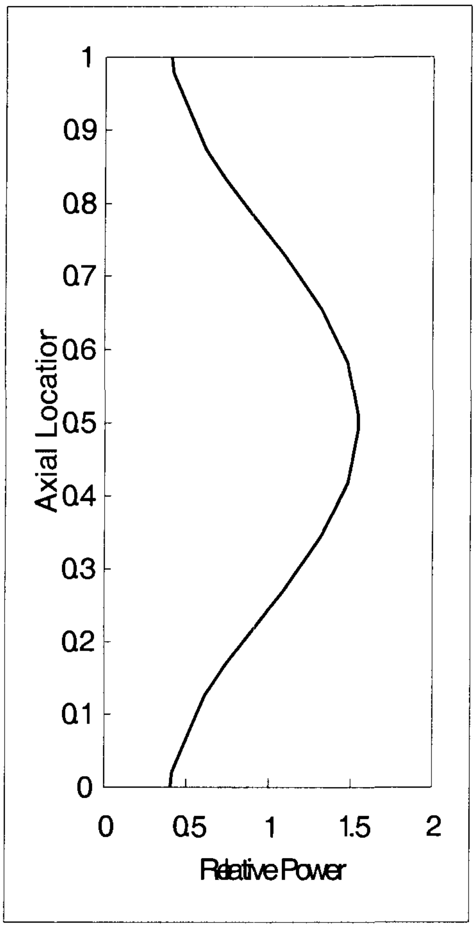

Figure 9 Water DNB Test Axial Power Distribution

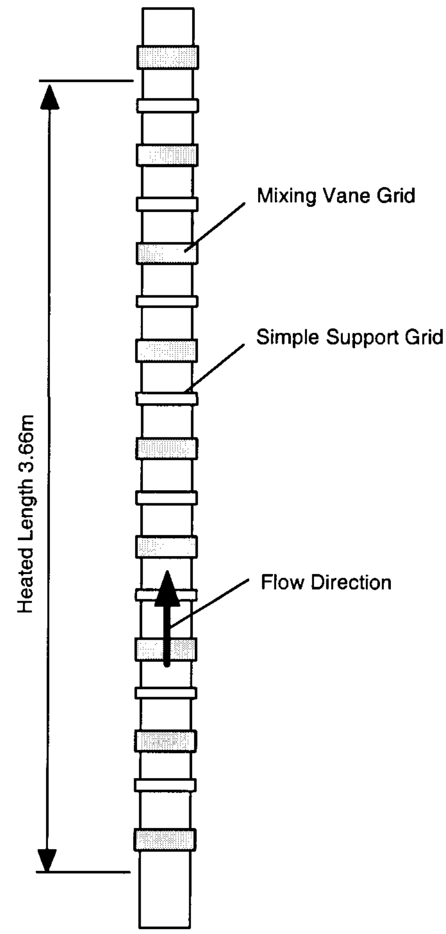

Figure 10 Water DNB Test Bundle Axial Configuration

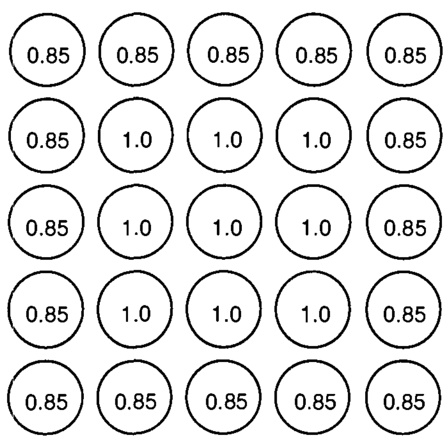

Figure 11 Water DNB Test Rod Power Distribution

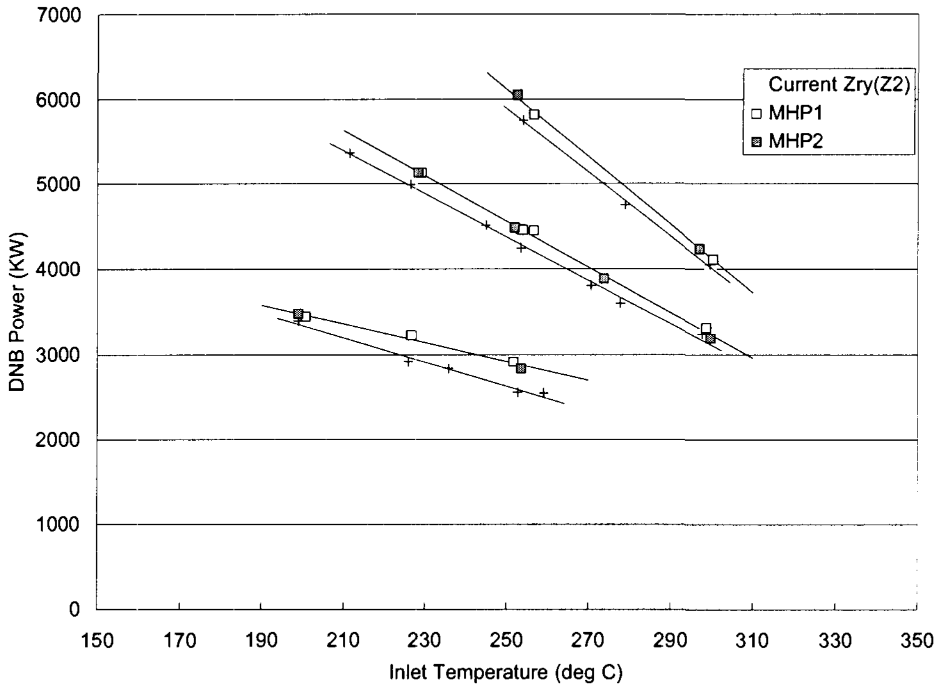

Figure 12 Water DNB Test Results (12.3MPa)

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