A Response Surface Method for the VHTR Optimization Design

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1. Introduction

Most modern engineering systems are multidisciplinary and their analysis is often very complex, involving hundreds of computer programs. This makes it difficult for users to decide which design optimization tool to use.

Optimization is one of the most powerful design improvement tools that are available today. There are many optimization programs are available nowadays. This paper presents one of the optimization programs that Response Surface Method for the VHTR optimization. This method will be applied successfully to design of VHTR systems.

2. Methods and Results

2.1 Objectives and Optimization of the VHTR

The objectives for Gen-IV are sustainability and economics, safety and reliability, proliferation resistance and physical protection. Because of economics, safety and reliability of this Gen-IV are indispensable conditions of the optimization, it is necessary for the new optimization methods. The following is one of reactor the worldwide is studying currently.

The VHTR (Very High Temperature Reactor) is under development for the purpose of massive hydrogen production using high temperature coolant over 950 ℃ as well as co-generation of electricity. The core bypass flow in the VHTR is one of the main technical issues in the design of the VHTR. It is critically necessary to minimize the amount of core bypass flow in order to improve the safety, efficiency and thermal margin of the reactor.

2.2 GAMMA+ code

The Gas Multicomponent Mixture Analysis (GAMMA) program is developed to predict the physical phenomena by following the expected postulated accidents in a High Temperature Gas Cooled Reactor (HTGR). Particularly, the program has a capability to calculate thermal-hydraulic transients as well as chemical reactions in a multicomponent mixture system. As a thermo-fluid system and network simulation code, GAMMA includes non-equilibrium porous media model for pebble-bed reactor core, general thermal radiation model, point reactor kinetics, and special component models. The special component models contain pump (or circulator), control systems, heat exchangers, turbine/compressor model, valve, general tables, etc. A block-oriented modeling approach is used which permits constructing complex systems using 1-D/2-D/3-D fluid and wall blocks.

2.3 Process Integration, Automation and Optimization

The integrated analysis procedure and automated design process made us easier to introduce the latest techniques to enables to build an optimal design. Therefore, it gives the advantage to reduce the cost and time to reach the high-quality engineering than the competitive products. Fig 1 below is a diagram explicating the application of the integrated tool for VHTR.

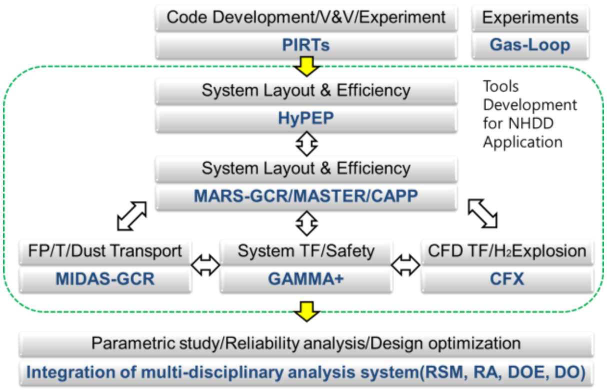

Fig 1. Integration of multi-disciplinary analysis system

2.4 Application of response surface method

The process of project was constructed with an environment is shown in Fig 2. First, the analyzer was used to figure out the relationship between variables and performances, and then the important design variables were selected with the rational data. This automatically generates the equation corresponding to the specified objective function and replaces the time-consuming analysis with the virtual model for the efficiently design. These approximating models are based on the experimental data or analysis result. After generating the virtual model, this data is applied to understand the design. There are four methods to understand (the) design: PS (parametric study), DSA (design sensitivity analysis), DOE (design of experiment), and RA (reliability analysis). Finally, the optimized data and optimized design are determined.

In this study, the following techniques were used: RSM (S-cubic), DOE (FFD), RA (LHS, 10,000 samples), and DO (STDQAO).

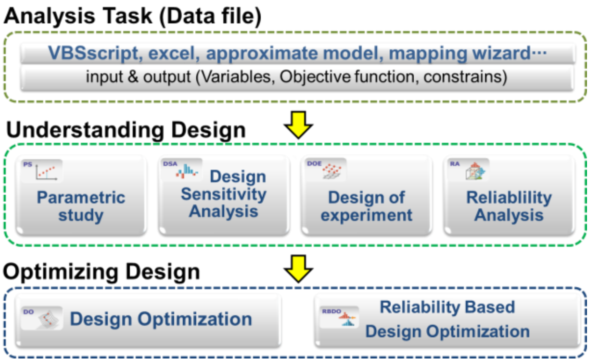

Fig 2. Process of optimization

Through this process, five kinds of equation methods are available. Generally, the exact value can be obtained by using the more complicated equation. Five variables and objective function are shown below.
(x1: Decay heat ratio, x2: Vessel emissivity, x3: RCCS emissivity, x4: RCCs loop junction area, x5: RPV heat transfer multiplier, G1: Temperature)
The below is the equations for VHTR (RSM).

1) Linear

$$Y=1099.683X_1-89.92362X_2-10.04017X_3-5.717118X_4-8.75147X_5+564.6174$$

2) Linear + interaction
3) Simple Quadratic
4) Full Quadratic
5) Simple Cubic

$$Y=-1071.923X_1^3-456.3190X_2^3-162.1656X_3^3+139.9939X_4^3-519.4841X_5^3+2834.649X_1^2+1132.872X_2^2+380.7688X_3^2-431.753X_4^2+1566.815X_5^2+61.46728X_1X_2+1.427511X_1X_3+184.3647X_1X_4-160.3702X_1X_5-33.94078X_2X_3-13.16536X_2X_4-66.75766X_2X_5-28.01503X_3X_4+56.20446X_3X_5-7.997859X_4X_5-1426.540X_1-973.0810X_2-309.1942X_3+290.6932X_4-1397.056X_5+1955.102$$

S-cubic shows that it best method to use and results are shown below.

Table I: The error of RSM equation

Equation	1	2	3	4	5
error	0.000997283	0.000927836	0.00095251	0.000899513	0.000841679

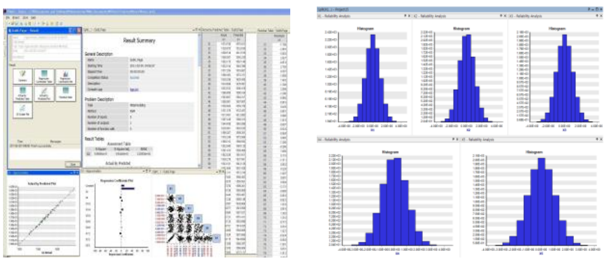

Fig 3. Result of RSM (S-cubic) and RA (LHS)

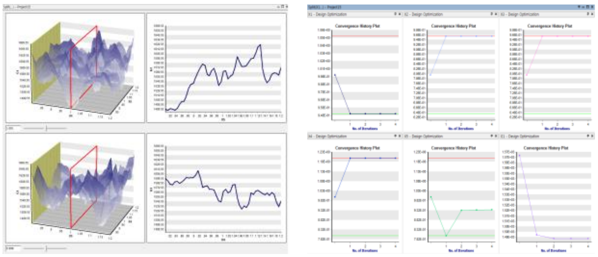

Fig4. Result of DOE (FFD) and DO (STDQAO)

Table Ⅱ: Optimization Result

		Lower bound	Initial value	Optimal value	Upper bound
Design Variables	x1	0.950	1.000	0.950	1.050
	x2	0.640	0.800	0.960	0.960
	x3	0.640	0.800	0.960	0.960
	x4	0.800	1.000	1.200	1.200
	x5	0.800	1.000	0.934	1.200
Objective Function	G1	-	1569.945	1491.725	-
Constraints	none	-	-	-	-

3. Conclusions

The Response Surface Method can be applied in many parts of nuclear engineering and developments expected. It is considered to save valuable work forces and time from many sampling and analysis, optimization.

In this way, we can apply RSM to MGR400 (conceptual VHTR design) developed by KAERI. It reduces analysis time to use approximation model made by RSM. Model analysis of this process takes more than 10 hours, which can be reduced within a few seconds. Either the uncertainty analysis or the optimization analysis, the model of the design process is performed for at least one hundred times. However, by utilizing the approximate models we can reduce much more time to analyze.

REFERENCES

[1] H. S. Lim, "GAMMA Multidimensional Multicomponent Mixture Analysis to Predict Air Ingress Phenomena in an HTGR", Nuclear Science Engineering, Vol.152, p. 87-97, 2006.
[2] Myers, R. H., and Montgomery, D. C., "Response Surface Methodology: process and product optimization using designed experiments", John Wiley & Sons. Inc., New York, 1995.