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Introduction

- ❖ In the reactor safety analysis, the application of system codes is important.
- ❖ Nuclear system analysis code has been developed to perform realistic multi-dimensional thermal hydraulic system analysis. More specifically, the MARS-KS code is used as widely accepted multi-dimensional thermal hydraulic tool. Code simulations are based on governing equations and constitutive equations. The constitutive equations are based on empiricism.
- ❖ Since, Nukiyama conducted a study on heat transfer with respect to temperature, steady research has continued. In wall heat transfer models, Nukiyama divided them into 4 regimes, RELAP code into 6 regimes, and MARS-KS into 6 regimes. Each regime has different constitutive equations. In MARS-KS, input variables of wall heat transfer (WHT) coefficients are 10, but regimes are divided by the logic of 5 variables. They are based on experiments but at the boundary, they are not continuous

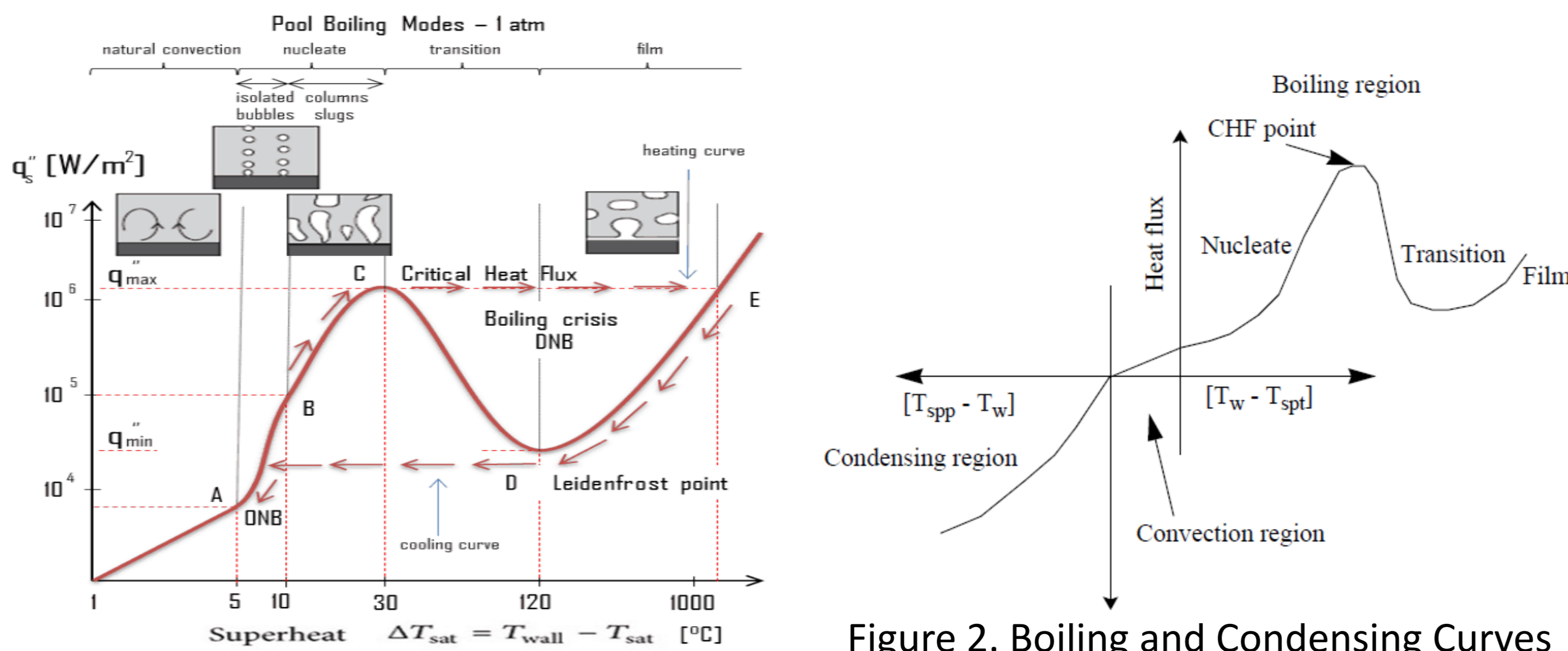


Figure 1. Boiling regimes of Nukiyama

- ❖ There is little knowledge of how to divide flow regimes and transition regimes. In this paper, the method of NEO-K-Means is applied to help to divide the flow regimes and transition regime.

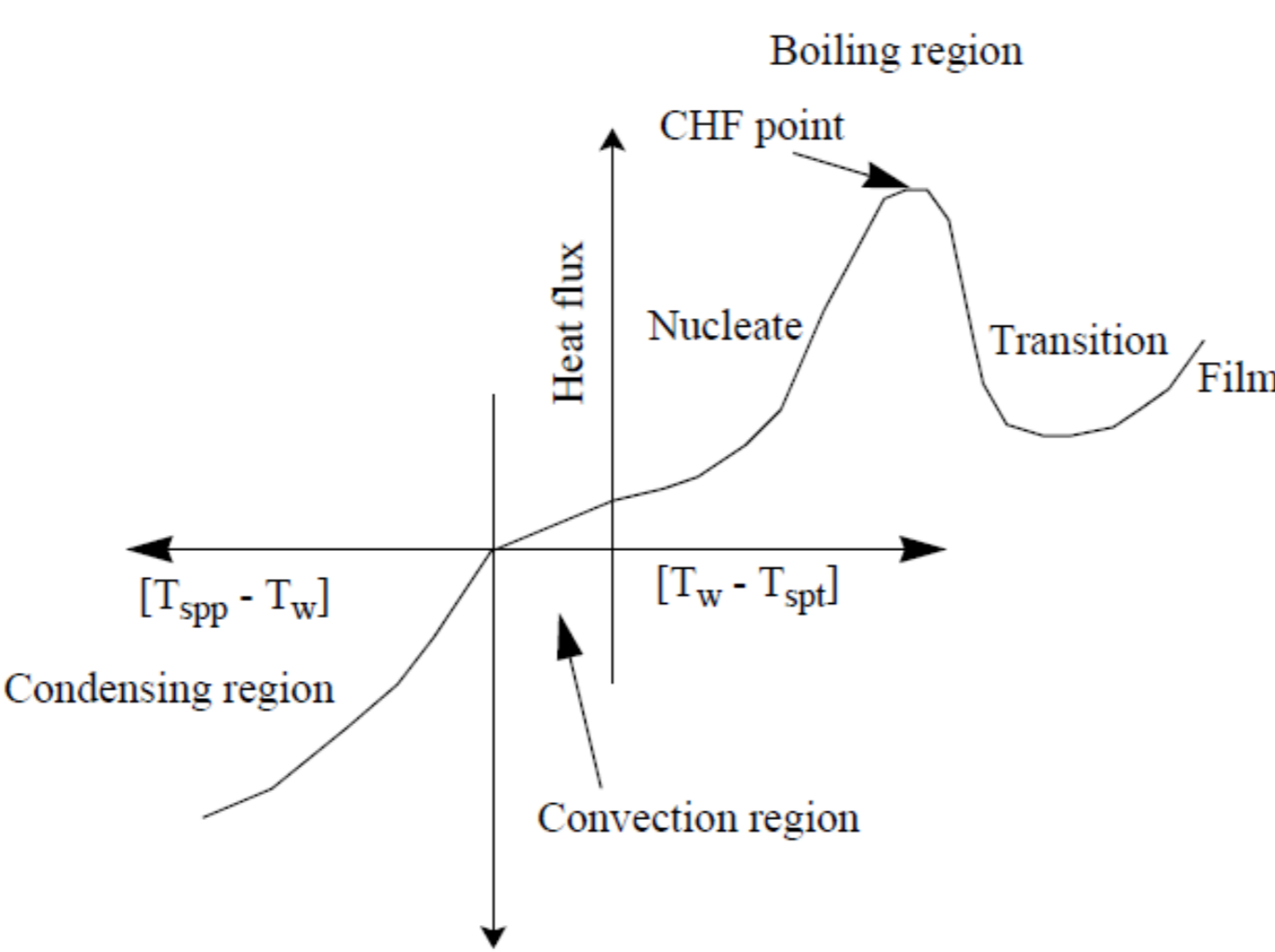


Figure 2. Boiling and Condensing Curves of MARS and RELAP5

Method

- ❖ K-Means
K-means algorithm is a typical clustering algorithm. It aims to cluster N data into k clusters. It assigns label into data and clustering based on labels. It assign the data to K clusters $S = \{s_1, s_2, s_3, \dots, s_K\}$ so that the difference in distance between the center of the cluster to which the data belongs is minimal. It is fast and distinguishes well for specific data.

- ❖ NEO-K-Means algorithm
In real world data, there are some data sets that are not clustered clearly, and others include noise. In the flow regimes, there are many ambiguous points between the regimes. People cannot experiment with all the detailed conditions. For these reasons, there are many ways to divide flow regimes. On the other hand, non-exhaustive, overlapping K-Means algorithms (NEO-K-Means) can divide over-lapping cluster and outlier.

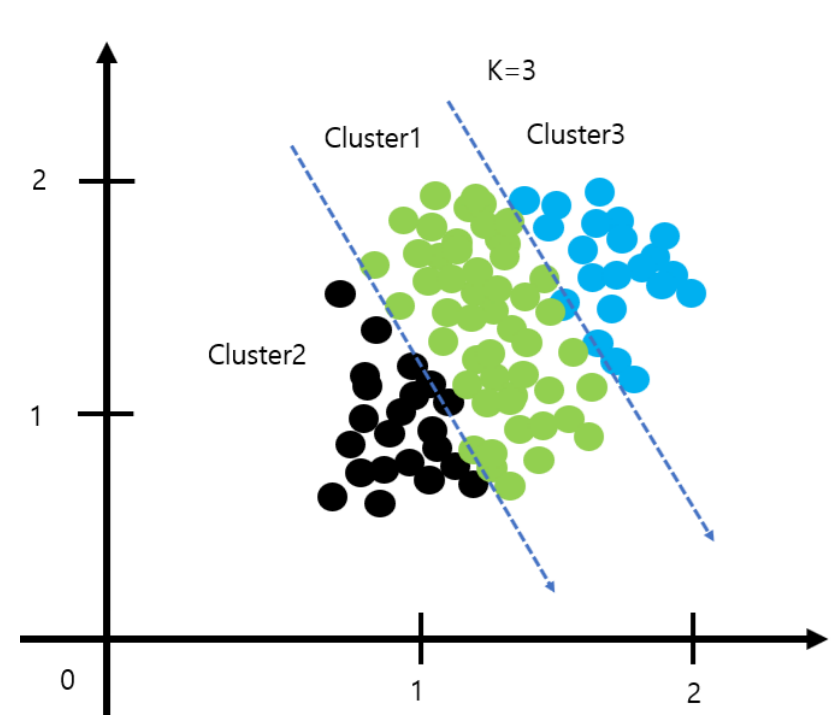


Figure 3. K-Means clustering

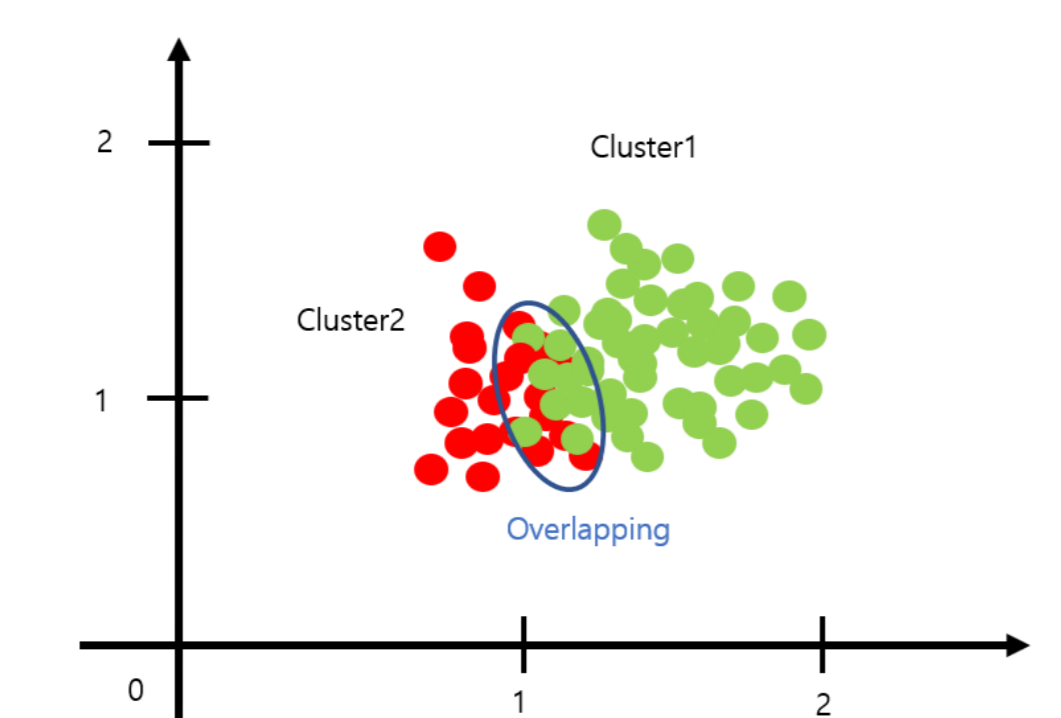


Figure 4. Clustering overlapping regime

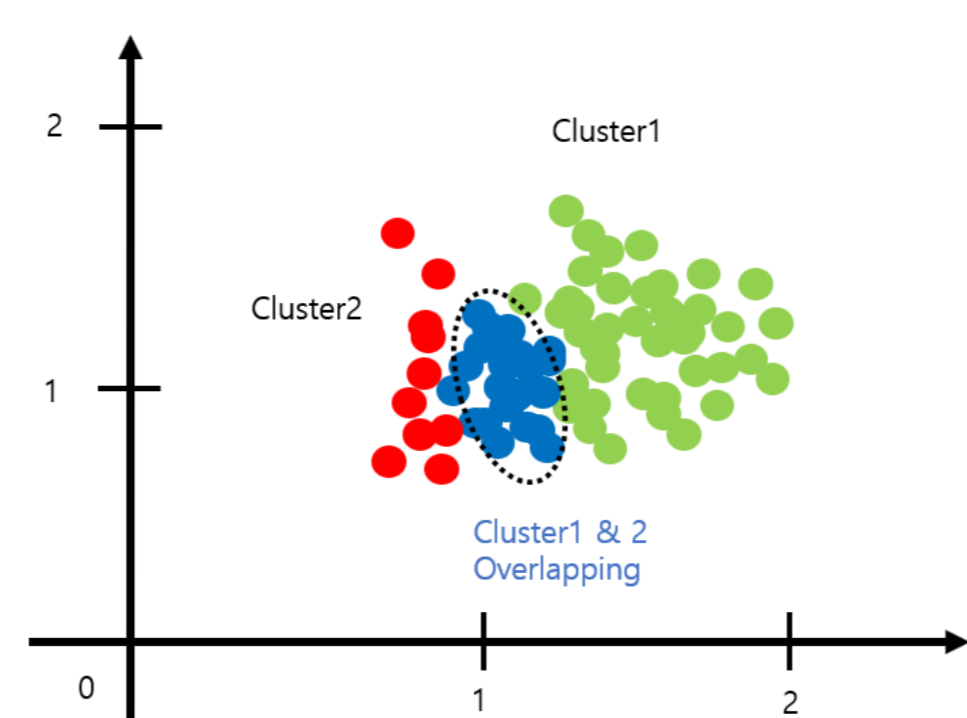


Figure 5. NEO-K-Means clustering

- ❖ Data

Data is selected to include the Design Basis Accident of the APR 1400 as much as possible. DBA accidents include LOCA, SGTR, and LOOP. They are interpreted through thermal hydraulic safety analysis codes.

Result

- ❖ The distribution of WHT using flow chart of MARS-KS
The WHT value was preprocessed as $\log(\text{value}+1)$

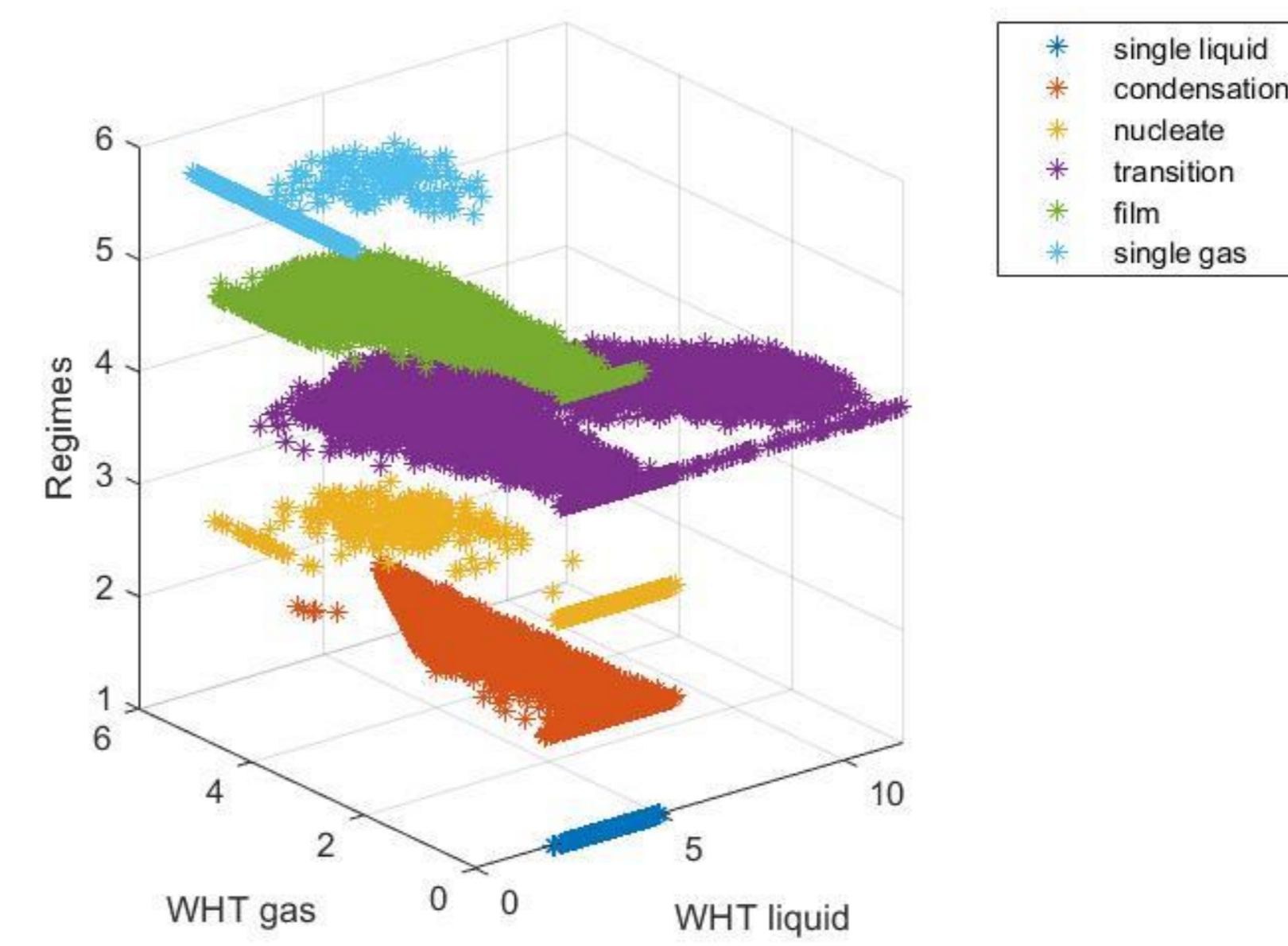


Figure 6. Distribution of MARS-KS data

Input parameters	Range
Pressure(MPa)	0.09 ~ 19
Fluid Temperature(K)	25 ~ (Tsat+50)
Wall Temperature(K)	25 ~ 1184
Void fraction	0 ~ 1
Mass flux(kg/m ² *s)	3 ~ 150
Slip Ratio	1 ~ 3
Hydraulic diameter(m)	8E-4 ~ 12
Volume length(m)	0.01 ~ 550
Angle(degree)	0 or 90
Roughness(m)	0~2.0E-4

Table 1. Range of Data

- ❖ Distribution of 2 regimes

Classifying regimes between single phase gas and single phase liquid using unsupervised learning is straightforward. This is because WHT of single phase liquid and WHT of single phase gas are mutually exclusive.

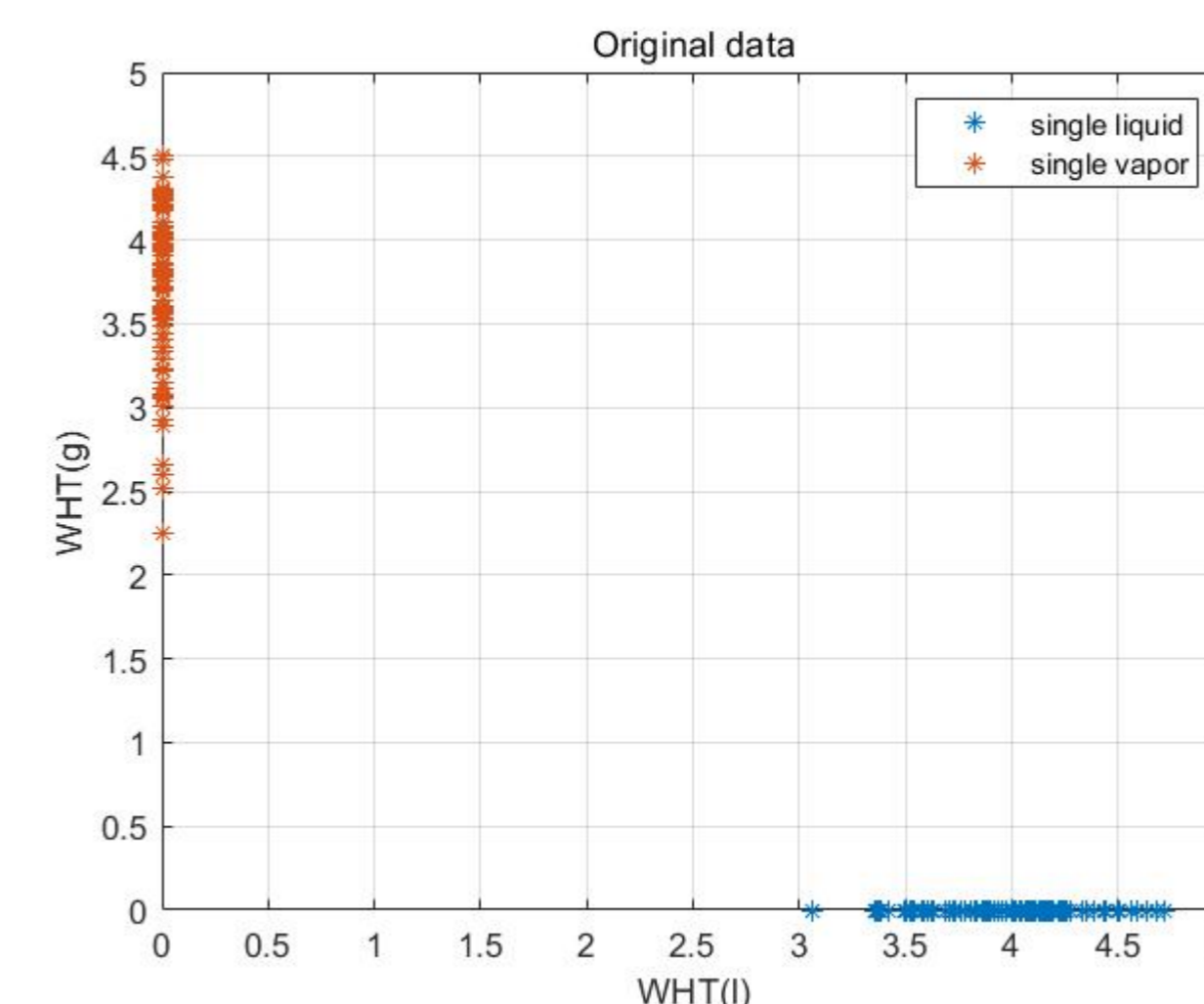


Figure 7. Distribution of MARS-KS data, 2 regimes

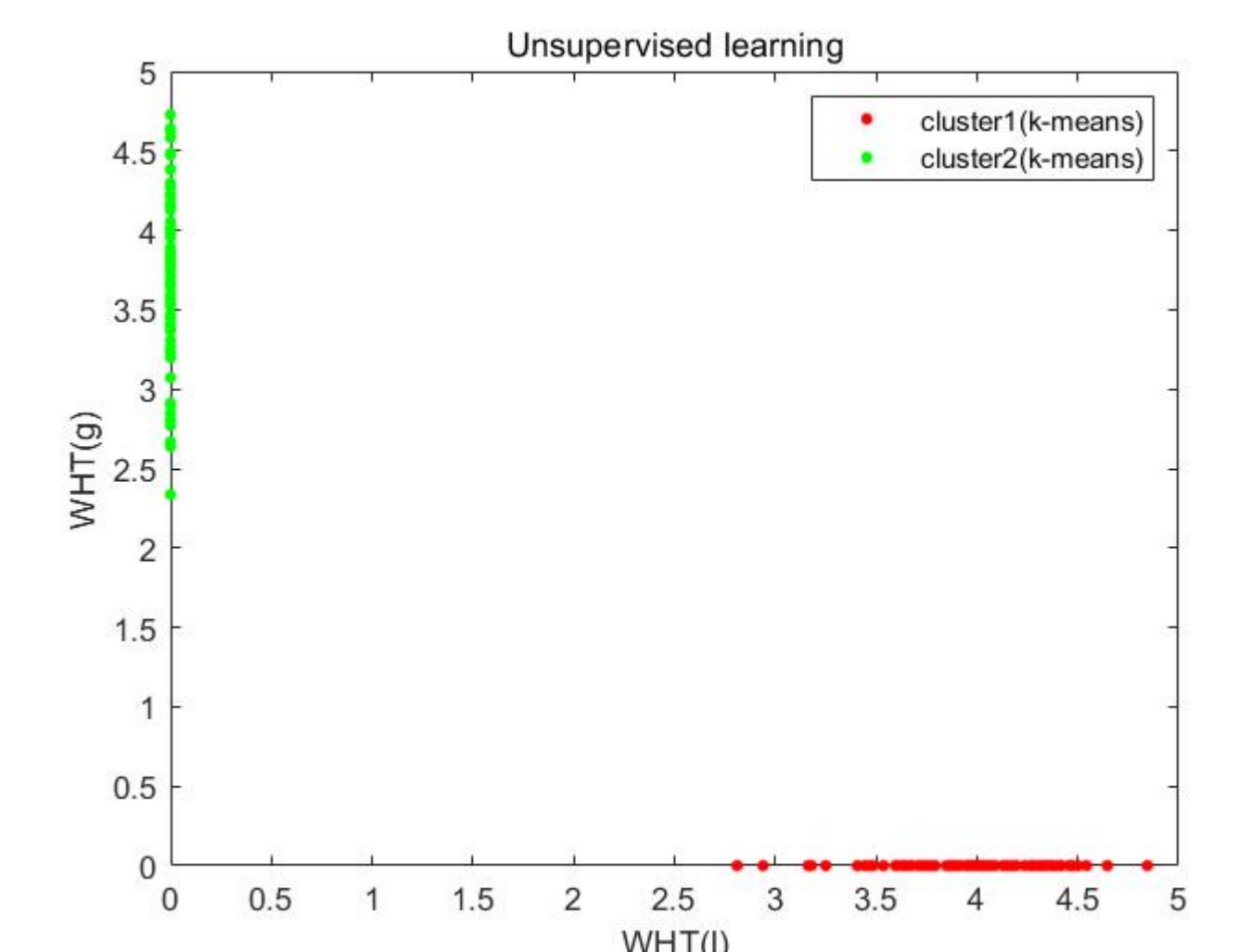


Figure 8. Distribution of unsupervised learning data, 2 regimes

- ❖ Distribution of 6 regime

However, classifying 6 regimes using unsupervised learning requires further research because WHT coefficient of 6 regimes are not mutually exclusive. There are several reasons.

- The calculation of WHT in the code sometimes involve arbitrarily determined interpolation and extrapolation.
- Another reason is that WHT values can be similar even for the different regimes.
- Since the code developer determined the heat transfer regime logic from indirect observation, this process involves a certain arbitrariness in this decision.

Thus, there is always a possibility that the regime classification may not agree with the observation of complete set of data.

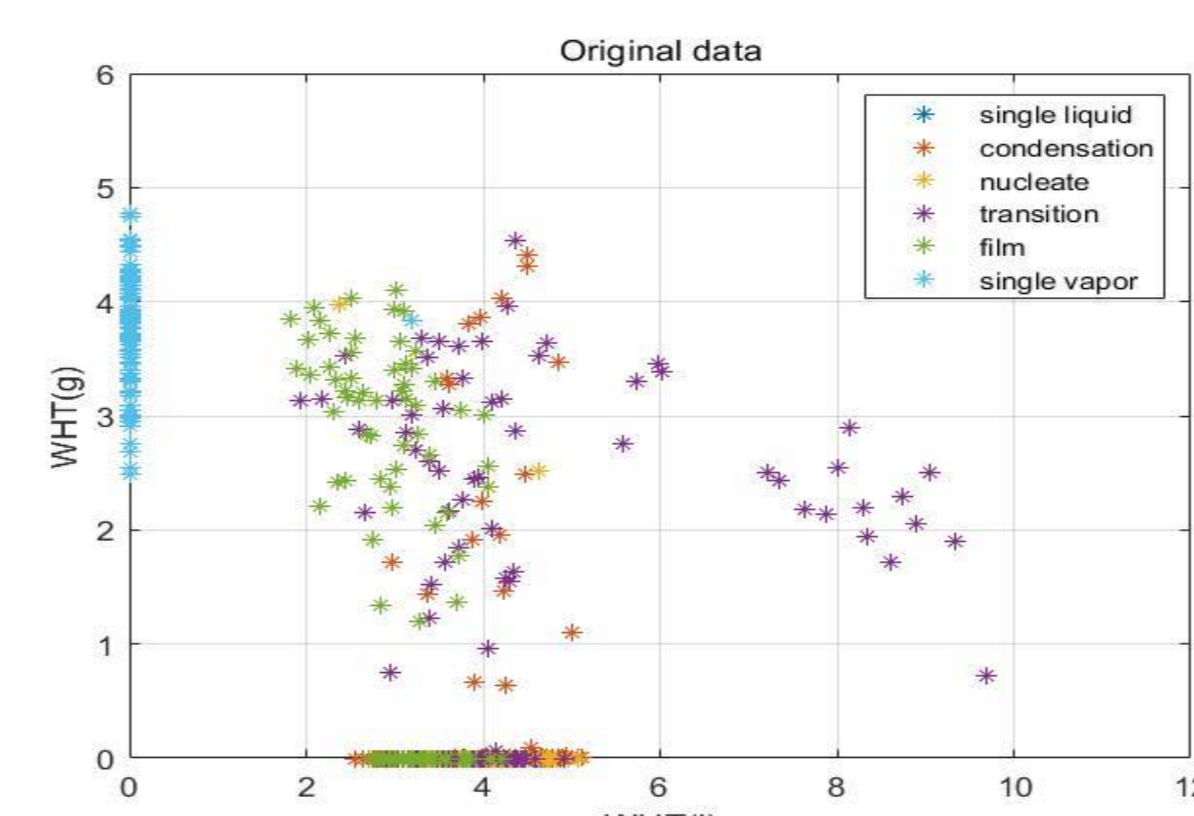


Figure 9. Distribution of MARS-KS data, 6 regimes

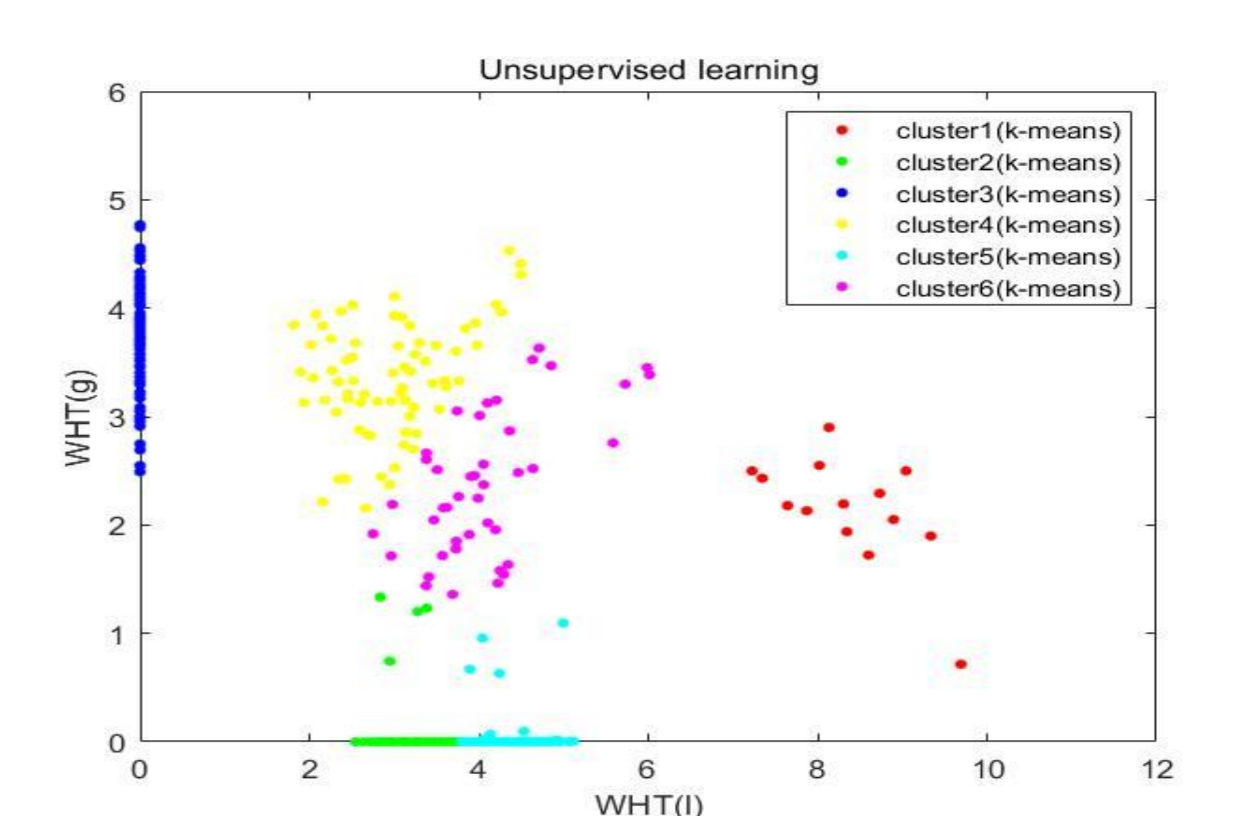


Figure 10. Distribution of unsupervised learning data, 6 regimes

Future works

- ❖ Finding the range of the experiment of WHT correlation
- ❖ Generating a data set that satisfies the direct experimental observation that corresponds to the valid range of the correlation.
- ❖ Neo-K-means will be used to classify the overlapping regime.
- ❖ Finally, the regime classification derived from unsupervised learning will be compared to the regime determined from algorithm implemented in the MARS code.