Chapter 4

Description of the Development

The development activity started with an optimum piping design method based on dynamic programming technique. According to the method, calculation algorithm was known and introduced what data necessary to be used. To make database schema, the design data was modelled as an object-oriented database model. After that, the POET software was used to develop the model to a piping database. A piping program was written by Visual C++ and linked with the database by including manipulation language.

Although various optimum design methods have been proposed to obtain solutions of this optimal design problem, the dynamic programming method is convenient to develop a program because it can solve complex network and yields the true optimum (see Chap. 2). Accordingly, this chapter presents the method of optimum piping design developed by dynamic programming technique and describes the object-oriented database model of piping data. At last, this chapter describes how to develop the program using POET and C++.

4.1 Development of Optimum Piping Design Method.

To develop an optimum piping design method that using dynamic programming technique, a basic structure for the design problem is developed and constructed as shown in Figure 4.1. From the figure, at i^{th} component of system, the different diameters to be considered are indexed by j.

a) Mathematical Model.

The objective function of the optimum piping problem is represented in a form of equation by referring to Eq. 2.22.

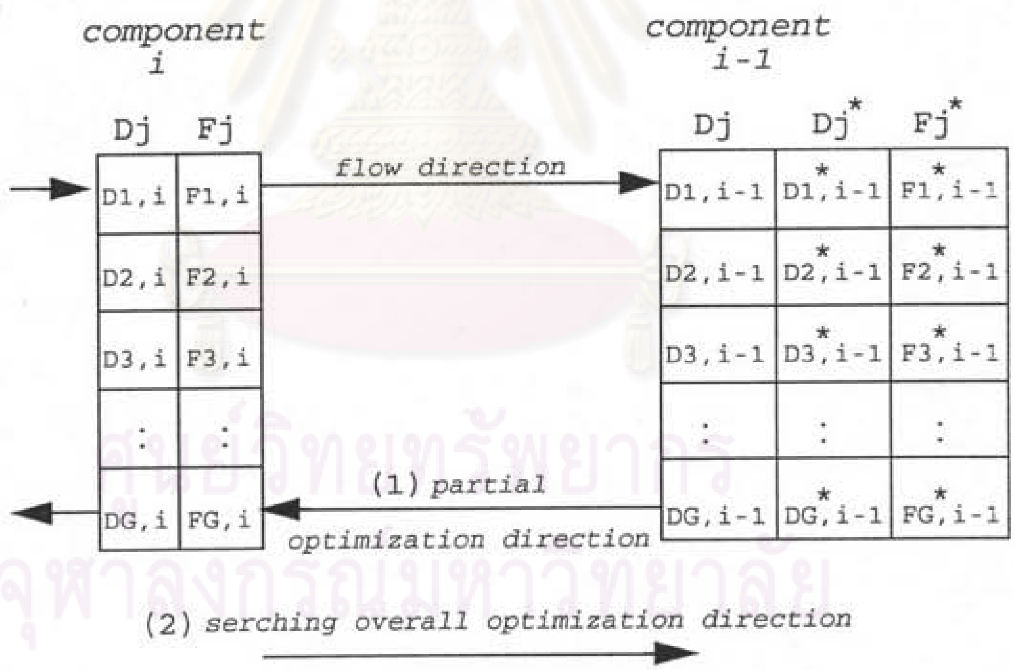

Figure 4.1: Searching optimal design diagram.

Hence,

$$\text{cost} = \min \sum C_{tj,i} = \min\{C_{tj,i}\} \qquad (2.22)$$

where

$C_{tj,i}$ = total annual cost of the jth diameter of the i^{th} component.

The recurrence formula for additive function can be expressed in equation form by referring to Eq. 2.25.

$$F^{*}_{j,i} = \min\left\{C_{tj,i} + F^{*}_{i-1}\right\} \qquad (2.25)$$

From figure 4.1, every diameter of i^{th} component selects the same set of choices, so the best choice is also the same diameter. Then the term $F^{*}{}_{i-1}$ in Eq. 2.25 is a constant and the term $F^{*}_{j,i}$ is only to minimum $C_{ti,n}$. Therefore, the size selection of i^{th} component is independent of n-1^{th} component. This method, each component itself can be determined to find its optimum diameter.

The optimum piping design data is built from analyzing total capital and pumping cost.

a) <u>Capital Cost.</u>

The capital cost of a component increases directly with diameter and depends on material, schedule and other component specifications. The basic cost consists of two principal items, purchased and installed cost. The purchased cost may be obtained from price lists and the installed cost can be often calculated by using a fraction of purchased cost. Moreover, the capital cost can be included some additional costs such as cost of insulation, painting, tracing, hangers, pipeways, etc. However, more details or accuracy would consume amount of time for calculations. The cost can be represented as

$P_{cj} = C_j$ for valves and fittings; (4.1)

$P_{cj} = C_j l_j$ for pipes; (4.2)

in which

P_{cj} = cost of the j^{th} diamemter;

C_j = purchased, installed cost and some additional costs of the j^{th} diameter, in cost per piece or cost per length of pipe;

l_j = pipe length of the j^{th} diameter.

At the end of project life, the salvage value of the j^{th} diameter may be expressed as a fraction of the original cost.

$$F_{sj} = sP_{cj} \tag{4.3}$$

in which

F_{sj} = salvage cost of the j^{th} diameter;

s = a fraction of original cost.

From time value of money, the equation can be form

$$P = \frac{F}{(1 + r)^{l_f}} \tag{4.4}$$

where

P = present value;

F = future value;

r = annual interest, as fractional rate per year;

l_f = number of years.

To determine present value of the j^{th} salvage, the term F in Eq. 4.4 can be replaced by F_{sj} from Eq. 4.3. Therefore,

$$P_{sj} = \frac{F_{sj}}{(1 + r)^{l_f}} \qquad (4.5)$$

in which

P_{sj} = present cost, the value now of the j^{th} salvage;

l_f = project life in years.

The total capital cost of the j^{th} diameter, P_{tj} is equal to subtract the salvage from the diameter cost. Hence,

$$P_{tj} = P_{cj} - P_{sj} \qquad (4.6)$$

From time value of money, annual value (A) can be determined in form

$$A = \frac{rP(1 + r)^{l_f}}{(1 + r)^{l_f} - 1} \qquad (4.7)$$

The term P in Eq. 4.7 can be replaced by P_{tj} from Eq. 4.6. Hence, annual capital cost is to be determined from

$$C_{pj} = \frac{rP_{tj}(1 + r)^{l_f}}{(1 + r)^{l_f} - 1} \qquad (4.8)$$

where

C_{pj} = annual capital cost of j^{th} diameter, in cost per year.

b) <u>Pumping Cost</u>.

Work is equal to the product of force and distance. In equation form,

$$\text{Work} = \text{Force} \times \text{Distance} \qquad (4.9)$$

The work delivered to fluid is calculated from weight (W) of fluid and the total head (H) developed by pump. It is defined by

$$\text{Work} = WH \tag{4.10}$$

Weight of fluid is equal to product of its mass (m) and the acceleration of gravity (g). In equation form,

$$W = mg \tag{4.11}$$

Power is the rate of work. In equation form,

$$\text{Power} = \frac{\text{Work}}{\text{Time}} \tag{4.12}$$

The term W in eq. 4.10 may be replaced by mg from Eq. 4.11. Therefore,

$$\text{Power} = \frac{mgH}{\text{Time}} \tag{4.13}$$

Mass is equal to the product of its density (ρ) and volume (V).

$$m = \rho V \tag{4.14}$$

Volumetric flowrate (Q) is a volume of fluid passing at a particular point per time. In equation form,

$$Q = \frac{V}{\text{Time}} \tag{4.15}$$

From eq. 4.14 and 4.15, the power in eq. 4.13 can be expressed as

$$P = \rho g Q H \tag{4.16}$$

where

P = pumping power

ρ = fluid density

Q = flowrate

H = pumping head

An electrical or other external source power providing to fluid power, may be defined as pumping power. In equation form

$$P = \frac{\rho g Q H}{E} \tag{4.17}$$

in which

E = conversion efficiency from electrical or other power source to fluid power.

The annual pumping cost will be given by:

$$C_{ep} = C_e T P \tag{4.18}$$

where

C_{ep} = power cost, in cost per year;

C_e = cost power, in cost per power-hour;

T = annual hours of pumping usage.

The term P in Eq 4.18 may be replaced itself by Eq. 4.17. Hence,

$$C_e = C_e T \frac{\rho g Q H}{E} \tag{4.19}$$

Piping system may be solved by including additional terms in *Bernoulli's equation* to represent pump energy (h_e) added. By using subscript 1 to denote suction point and subscript 2 to denote discharge point, this piping system can be expressed in equation form

$$\frac{p_1}{\rho g} + \frac{v_1^2}{2g} + z_1 + h_e = \frac{p_2}{\rho g} + \frac{v_2^2}{2g} + z_2 + \sum_{n'} h_f \tag{4.20}$$

where

p_1 and p_2 = pressure at points 1 and 2, respectively;

v_1 and v_2 = velocity at points 1 and 2, respectively;

z_1 and z_2 = elevation of points 1 and 2, respectively, above a reference datum;

h_e = energy head added to a piping system;

h_f = head loss;

The headloss summation over n' is taken over all piping components in the flow path.

Head loss due to pipe friction can be determined by *Darcy's equation*:

$$h_f = f\frac{lv^2}{D2g} \tag{4.21}$$

where

f = friction factor

l = pipe length

D = inside diameter

v = velocity of flow

Total head is the sum of pressure head, velocity head and elevation. Then Eq. 4.20 can be modified to express in terms of total suction head (H_s) and total discharge head (H_d) as

$$H_s + h_e = H_d + \sum_{n'} h_f \tag{4.23}$$

Hence, pump head may be rearranged to give

$$h_e = \left(H_d - H_s\right) + \sum_{n'} h_f \tag{4.24}$$

From Eq. 4.17, power can be equal to ρgQH. Then the pumping power can be expressed as

$$P_{pump} = \left(\rho_d g Q_d H_d - \rho_s g Q_s H_s\right) + \sum_{n'} \rho g Q h_f \qquad (4.25)$$

The sum of $\rho g Q h_f$ is taken over all power of piping components between pump station and discharge point. Therefore, power supplied to move fluid through the jth diameter, may be expressed as

$$P_j = \rho_j g Q_j H_j \qquad (4.26)$$

The pumping cost can be expressed as

$$C_{ej} = C_e T \frac{\rho_j g Q_j h_{fj}}{E} \qquad (4.27)$$

where

P_j = fluid power of the j^{th} diameter;

ρ_j = fluid density of the j^{th} diameter;

Q_j = fluid flowrate of the j^{th} diameter;

H_j = total head of the j^{th} diameter.

Therefore, the annual pumping cost of pipe can be expressed in term of length as

$$C_{ej} = C_e T f_j \frac{\rho_j Q_j}{E} \frac{l_j v_j^2}{2Dj} \qquad (4.28)$$

c) <u>Total Cost.</u>

Total cost of piping system (C_{sys}) is the sum of annual cost of piping components and annual cost of pump which can be expressed as

$$C_{sys} = C_{t,pump} + C_{e,pump} + \sum C_{tj} \qquad (4.29)$$

where

$C_{t,pump}$ = annual capital cost of pump;

$C_{e,pump}$ = annual pumping cost of pump due to head different between pump head and friction head;

C_{tj} = annual total cost of piping component which equals to sum of C_{pj} and C_{ej}.

4.2 Development of Piping Database Model.

A program using database is an effective system because it can call the database and reads/writes the desired data directly. Figure 4.2 illustrates program and database interface.

Figure 4.2: Program and database interface.

To develop the program, program functions and database have to design correspondingly.

4.2.1 Program Functions.

This program can be preceded like the actual design. The first step of common actual design is the piping network layout that shows how demand points are connected to the source. Piping components such as pipes, elbows, tees, valves, reducers are identified and specified in terms of material, schedule and other description data. After that, demanded flowrate is defined at end of each branch and commercial pipes, valves and fittings are prepared for selection. Cost analysis calculation data such as annual interest, project life, operation hour, power cost and pump efficiency are specified.

The developed program formed steps of the actual design into four functions.

- Process Configuration
- Pipe, Valve and Fitting Data
- Specification
- Calculation

Data such as component number, inlet component, outlet component, component type, minimum required pressure, elevation which described process diagram was directed by process configuration function. Candidate commercial data such as pipe, valve and fitting data was managed by the program function of pipe, valve and fitting data. For the optimum design, data such as fluid properties and cost analysis data were specified by the function of specification. The optimum solution was calculated by the calculation function.

These program functions were able to store or retrieve required data among them by using database. The program functions and database can be represented as in Figure 4.3.

4.2.2 Piping Database Model.

A piping system has many piping components. From object-oriented database model technique (presented in Sec. 3.1.4), piping model can be shown in Figure. 4.4a. Member of the *Piping System* object class is a set of *piping components* and the pieces of piping components are distinguished by number. The piping component may be a piece of pipe, elbow, tee, valve or reducer.

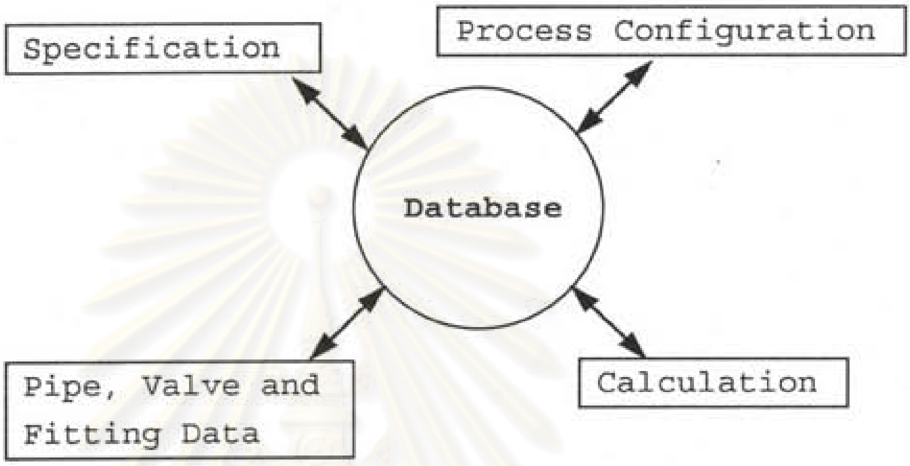

Figure 4.3: Program functions and database.

The piping system object class stores general information for design. It has a name, annual interest, project life, operation hour, power cost and pump&driver efficiency as shown in Figure 4.4b.

The *Piping Component object class* contains general information (Figure 4.4c). *Pipe, elbow, tee, valve, and reducer object classes* store specific information (Figure 4.4d-h). The general information is component number, inlet stream number, outlet stream number-1, outlet stream number-2, fluid density, fluid viscosity, fluid flowrate, pumping cost, total cost.

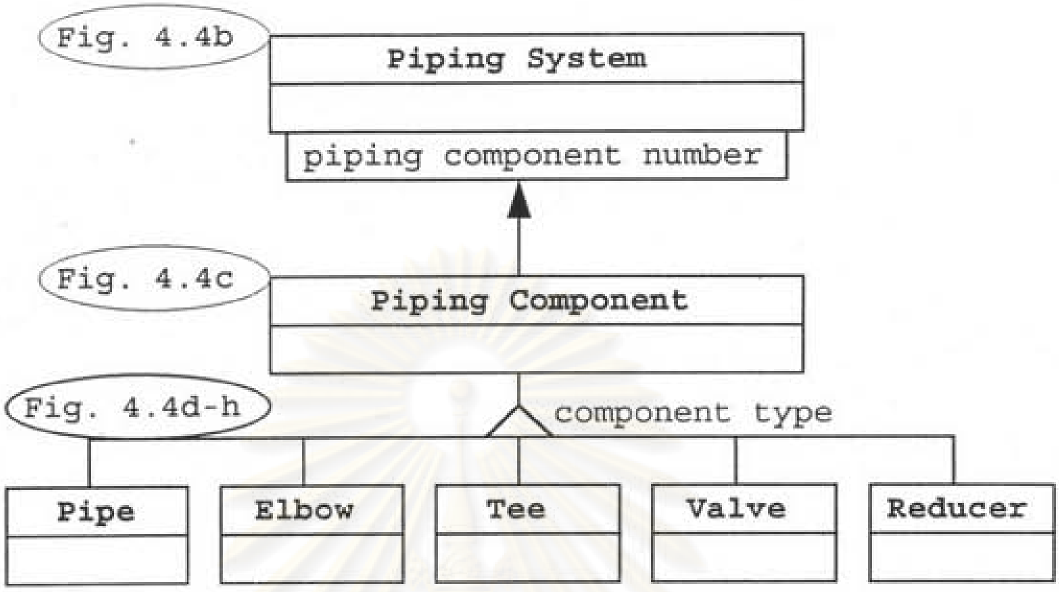

Figure 4.4a: Piping model.

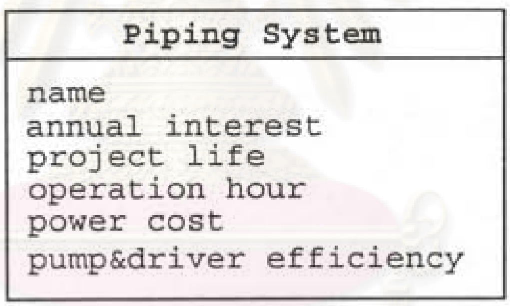

Figure 4.4b: Piping model.

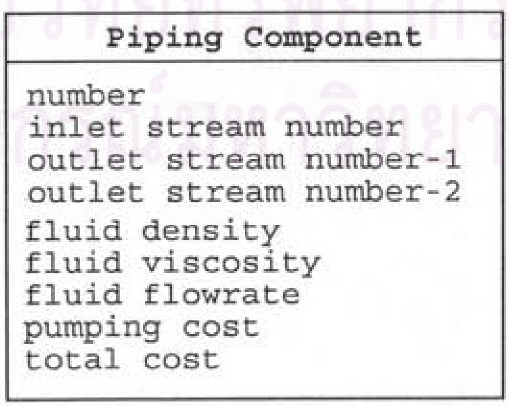

Figure 4.4c: Piping model.

Pipe
material joint schedule NPS inside diameter roughness cost length

Figure 4.4d: Piping model.

Elbow
material joint type NPS *k* cost

Figure 4.4e: Piping model.

Tee
material joint type NPS *k* cost

Figure 4.4f: Piping model.

Valve
material joint type NPS %close *k* cost

Figure 4.4g: Piping model.

Reducer
material joint type small NPS large NPS *k* cost

Figure 4.4h: Piping model.

The specific data is mainly modelled to support commercial pipe, valve and fitting data that prepared as choices for optimum selection. The data can be described as follows:

Pipe Data.

1) *Material*. Pipe materials can be divided into two main classes, metal and non-metal. The metal materials are cast, malleable, and high silicon irons; carbon steel and low- and intermediate-alloy steels; high-alloy (stainless) steels; nickel and nickel-base alloys; aluminium and aluminium alloys; Copper and copper alloys;

and etc. The non-metals are thermoplastics, reinforced thermosetting resin, asbestos cement, etc.

2) *Joint*. There are several joint techniques but only three kinds of joints are commonly used: threaded joints, welded joints and flanged joints.

3) *Pipe Schedule Number*. The American Standards Association has set up specifications for wall thickness by schedule number that is a function of internal pressure and allowable stress. Ten schedule numbers are in used: 10, 20, 30, 40, 60, 80, 100, 120, 140, and 160 but only schedule number 40, 80, 120, and 160 are stock items for steel pipe less than 8 inch size.

4) *Nominal Pipe Size (NPS)*. Piping is specified in terms of a nominal pipe size or diameter that related to an outside diameter independent of the schedule number or wall thickness. The nominal pipe size of steel pipe ranges from 1/8 to 30 in.

5) *Inside Diameter*. Nominal pipe size is neither the actual inside nor outside diameter but the nominal pipe size of large pipe is close to the actual outside diameter.

6) *Roughness* (ε). In turbulent flow, a rough pipe leads to larger friction head than a smooth pipe. Roughness depends on the kind of material and its condition.

7) *Cost*. The cost is the capital cost, C_j having unit in cost per length of pipe.

Elbow Data.

1) *Material*.

2) *Joint*.

3) *Type*. There are several types of elbow: 45^o regular, 45^o long radius, 90^o regular, 90^o long radius, etc.

4) *NPS*.

5) *Resistance Coefficient* (k). It is convenient to use the resistance coefficient to determine friction loss from valve&fitting obstruction.

6) *Cost*. For valves and fittings, the capital cost, C_j has unit in cost per piece.

Tee Data.

1) *Material*.

2) *Joint*.

3) *NPS*.

4) *Resistance Coefficient* (k).

5) Cost.

Valve Data.

1) *Material*.

2) *Joint*.

3) *Type*. There are several types of valve: gate, globe, angle, etc.

4) *NPS*.

5) *%close*. The percentage of valve may be 0(open fully), 25, 50, 75, etc.

6) *Resistance Coefficient* (*k*).

7) *Cost*.

<u>Reducer Data.</u>

1) *Material*.

2) *Joint*.

3) *Type*. There are several types of reducer such as concentric, eccentric.

4) *Small NPS*.

5) *Large NPS*.

6) *Resistance Coefficient* (*k*).

7) *Cost*.

Therefore, the developed program was designed and used data following figure.

4.2.3 <u>C++ Program and POET Database.</u>

According to the piping database model, piping database was developed by using POET Release 2.0, object-oriented database, of POET Software Corporation. There were many commercial object-oriented databases such as ORION(ITASCA) of Advanced Computer Technology, GEMSTONE of Servio, Inc., ONTOS of Ontons, Inc., ObjectStore of Object Design, Inc., and VERSANT of Versant Object Technology Corp.

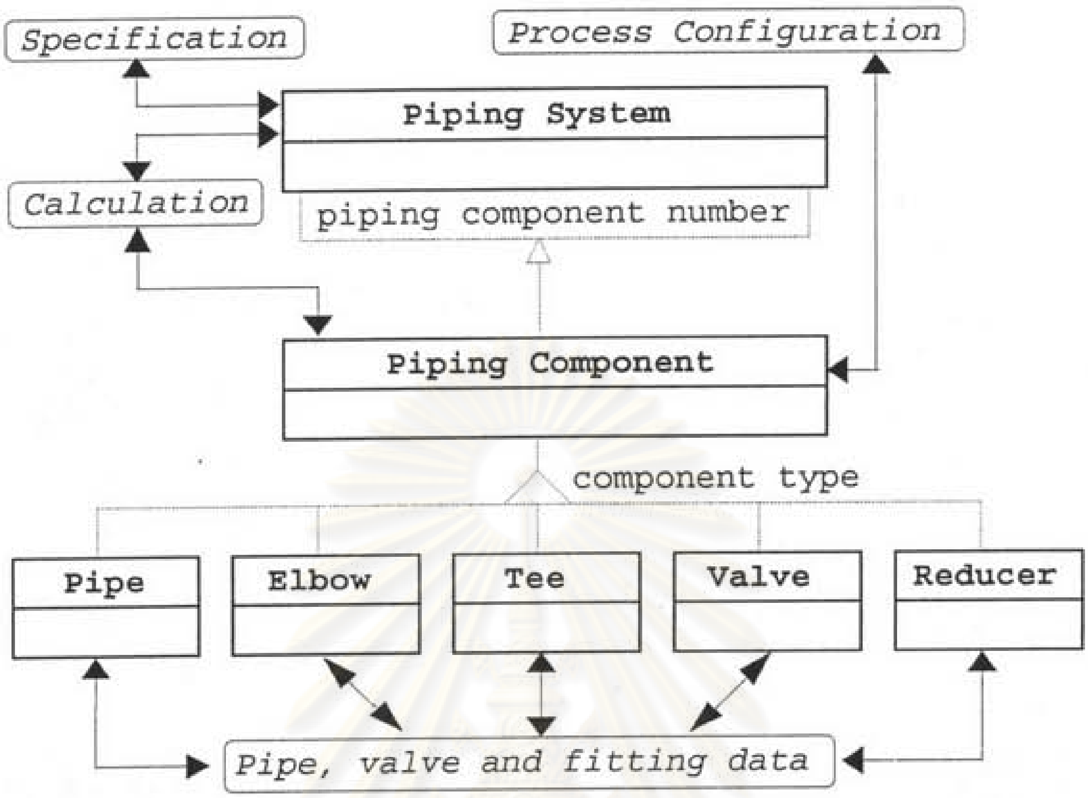

Figure 4.5: Integration of program process and database model.

However, the POET was selected because it not only provided facilities of object-oriented database but it was also scalable across various platforms, i.e., DOS, Windows, NT, MAC, and OS/2. Therefore, POET Personal Edition for Windows was used to develop the piping database. Because the POET supported Microsoft Visual C++ 1.0, the piping program was develop by using C++.

To create the piping database, classes of the piping model were written in *.hcd file like C++ classes. The POET executed the *.hcd file and then built a piping database with files, *.hxx and *.cxx, for managing the database. After that, the piping program files were written and linked with the piping database by including the *.hxx and *.cxx. Finally, the Visual C++ built all piping program files to a piping program that was able to manage piping data.