An internet-based working fluid properties database

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In this paper, an internet-based working fluid property calculation system is proposed. An internet database is set up and a series of programs using database method to calculate the properties of working fluids are developed. To validate the system, property databases for Nitrogen and Oxygen were set up. In the programs, special attention was paid to some special conditions. These conditions might appear when the points to be calculated are near two-phase area. A set of correction methods to deal with these points are developed. Lastly, the calculation error is assessed by two different methods.

INTRODUCTION

The methods to calculate thermal properties of working fluids can be divided into two categories: database method and equation method. Equation method uses equations of working fluid state to get the properties of unknown state points. The programs developed on basis of this method are compact and flexible. But to develop this kind of program needs a lot of works and large numbers of iterations are used in the calculation which makes the calculation relatively slow and unstable. Another kind of method, database method, has no such shortcomings. This method depends on interpolation to get the unknown properties on specific state point. This is feasible because the property of working fluid in a single phase is continuous. But this kind of method has the disadvantage that a property database consumes relatively large space in computer. With the developing of internet technology, we can solve this problem by using internet database. The database could be stored in an internet server. Users get necessary information from the server through internet and complete the calculation at either the server side or the user side. This calculation system avoids complex processing of the properties data got by experiments. At the same time, no iteration is needed and no special software is needed on the user's computer but internet browsers only.

DATABASE METHOD FOR PROPERTY CALCULATION

In the database, properties data on discrete state points are stored in a series of data tables which are arranged by pressure and temperature. To calculate the thermophysical properties of a state point, the phase of the point is confirmed firstly by comparing the known properties such as pressure and enthalpy of the point with the data in the saturation curve table. Then the nearest points to this specific point in the database are found out whose properties are already known. The number of needed surrounding points is determined by the method used for interpolation, typically linear or least square interpolation. Then the properties of these points are interpolated to get the unknown properties of the specific point. For example, if we want to

know enthalpy of nitrogen at p=2.5MPa，T=273K, and bilinear interpolation is adopted, the calculation process is shown in Figure 1. In the figure, points 1, 2, 3 and 4 stand for the nearest known points to the point to be calculated. Points 1 and 4 have the same pressure while points 2 and 3 have the same pressure. This convention is followed for all the subsequent methods. The equation is:

$$h = \left[\frac{T - T_1}{T_4 - T_1}(h_4 - h_1) - \frac{T - T_3}{T_3 - T_2}(h_3 - h_2) \right] \frac{p - p_2}{p_1 - p_2} \tag{1}$$

If the known properties are pressure and enthalpy, the state point may be located in two-phase area. In this case, dryness number x is calculated firstly and is used to calculate other properties. The calculation process is shown in Figure 2.

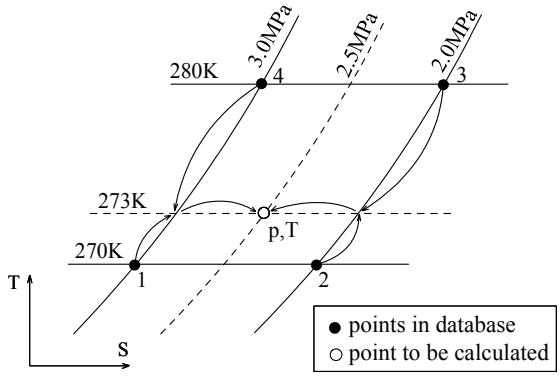


Figure 1 Basic calculation process

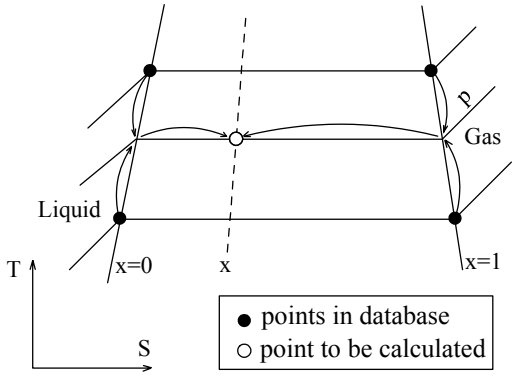


Figure 2 Case of two-phase area

SYSTEM STRUCTURE

In the system, web browsers such as Internet Explorer are used as user-interface to input calculation condition. The web browser transfers these data to the web server. Programs at the server-side then carry out calculation and transfer readable results back to the web browser. The structure of the system is shown in Figure 3.

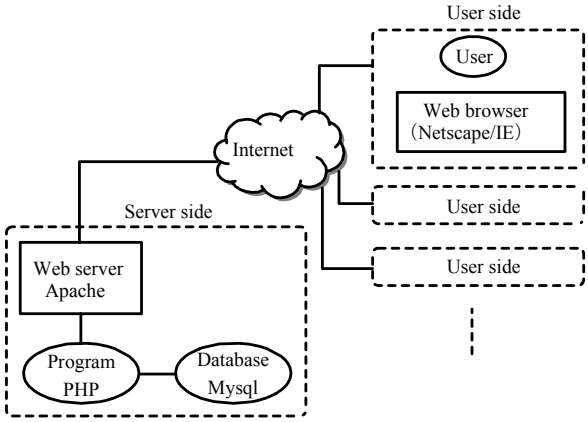


Figure 3 Structure of the system

Apache is used as web server in the current system. The database is developed on the basis of Mysql which has good compatibility with different operation system. Calculation programs and user interface are developed with PHP and JavaScript. The entire developing environment is free of charge which decreases the cost of the system.

STRUCTURE OF THE DATABASE

In the current system, property database for oxygen and nitrogen has been set up. The tables store the values of density, compressibility, enthalpy, entropy, isochoric and isobaric specific heat for the liquid and gaseous phases and on the solidification and saturation curves. An additional field “con” is added to the table to indicate the phase state of the point. The value of “con” may be 0, 1 or 2, which respectively stand for liquid area, gas area and the area whose temperature or pressure is higher than the critical point. We use the data from [1] and [2] which is supposed to be very reliable. The data are arranged by temperature and

pressure. Table 1 is part of the data tables. The points are in the temperature interval from the triple point to 1500K and pressures between 0.1 and 100 MPa. An independent table is used to store the data of points on saturation curve. All the values are in SI units.

Table 1 Structure of the database (Oxygen)

T (K)	p (MPa)	ρ (kg/m^3)	z	h (kJ/kg)	s (kJ/(kg·K))	c_v (kJ/(kg·K))	c_p (kJ/(kg·K))	*con*
				…				
135	20.0	976.37	0.5840	226.9	3.537	0.831	1.710	2
135	21.0	980.40	0.6106	227.2	3.532	0.831	1.710	2
				…				
140	20.0	950.78	0.5783	235.5	3.600	0.824	1.735	2
140	21.0	955.29	0.6043	235.8	3.594	0.824	1.721	2

SPECIAL POINTS

Because the data tables are arranged by temperature and pressure, points of different phase are successive in the table. So the points to be interpolated may be located in different phase, which may lead to large error. Special steps must be taken to treat with these conditions. The following methods are based on two-dimensional linear fit.

The case can be divided into 2 categories according to the phase of the point to be calculated. To be concise, only the case of gas phase will be illustrated here. The case of liquid phase is similar to the case of gas phase.

The rule of the methods to treat with these special conditions is to discard the points whose phase is not the same as the point to be calculated and replace them with appropriate point in the saturation curve table. For example, in Figure 4, although the point 1, 2 and 4 is the nearest points in the data table to the point to be calculated, they are in different phase. So we replace them with the points on saturation curve that have the same temperature and pressure with the point to be calculated and use them in interpolation.

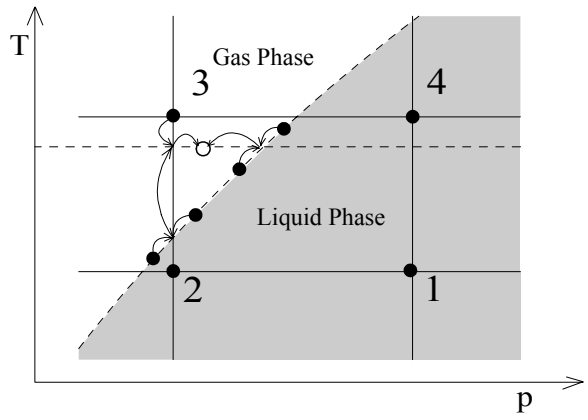


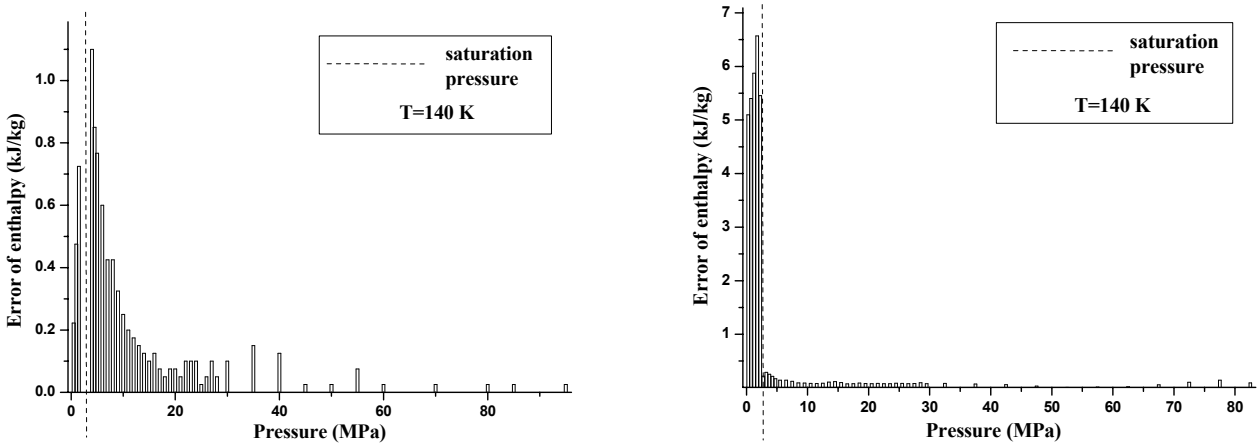
Figure 4 Processing of special points

Totally there are 12 special conditions to be considered. In fact, we find that these conditions can be processed with only six sub programs which can make the program compact and the calculation more efficient.

ERROR ASSESSMENT

Two methods of error assessment are used to check the accuracy of the system. The first could be called self-comparison method. A known point in the database is calculated by the system and then compared with itself. Figure 5a shows error of enthalpy assessed by this method when temperature equals to 140K. It can be found that in area far from double phase area, error of enthalpy calculated by the system is less than 0.8kJ/kg. In the area that is near to double-phase area, the error may be too high to be acceptable. To solve this problem, the density of points in this area should be increased in the database and higher order

interpolation such as bicubic interpolation should be adopted. But higher order interpolations need more points in calculation. For example, bicubic interpolation uses an average of 16 surrounding points. At the same time, conditions will be much more complex near double-phase area. The second method is to compare the calculation result with the result of the calculation program recommended by [3]. Figure 5b shows the deviation of enthalpy assessed by this method. The conclusion is similar to that of method 1.



(a) method 1 (b) method 2

Figure 5 Error assessment of enthalpy

To check the accuracy for changes in properties over smaller temperature and pressure steps than the step size of database, we calculated the enthalpy change while temperature changes from 137K to 139K and pressure change is half of the database step size. The result is compared with [3] and shows a highest relative error of 4.7% while in most cases the error is less than 1.0%.

CONCLUSION

An internet-based working fluid property calculation system has been set up and the error of the calculation is assessed. The result shows that to calculate the thermophysical properties of working fluids through internet is feasible and the error is acceptable if the density of points in database is high enough.

ACKNOWLEGEMENT

This work was supported by the National Key Project of Fundamental Research of R & D of China (G2000026303) and the National Natural Science Foundation of China (50276046).

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