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A NOVEL METHOD AND PROCEDURE FOR ON-LINE MEASUREMENT OF FLUID PROPERTIES FOR CONTROL AND OPTIMIZATION

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Abstract. This work describes an on-line method and procedure for calculating the fluid properties in real time while system is in operation. The method utilizes function blocks of distributed control systems. Thermodynamic relations of fluid from tables along with a fluid property formula are imbedded into the proposed signal processing block. Once the pressure and temperature measurements are entered the system provides other properties.

1. Introduction

The measurement of fluid properties in real time is the key for providing an efficient operation especially in energy systems. In this work, the values of properties such as specific volume, enthalpy, entropy are developed by using alternate methods which require only function blocks of distributed controls. Thus, this method can be used readily in feedback and real-time optimization of energy systems while the process is in operation. Also, the measurement of heat flow through a conduit can be determined once the thermodynamic properties of fluid as proposed here is found by the flow measurement techniques [1].

There are numerous optimization methods to determine the fluid properties such as for steam by Beattie-Bridgman (B-B) Equations [2], or by storing the fluid tables in computer memories. A design engineer can effort this luxury while designing an energy system in an office environment. However, in an actual operation, such properties should be and can be determined readily (on-line) by using alternate novel methods as will be described. This method works without an optimization software and without a high level computer language which needs compilation. That is, the method works as if it is an on-line measurement device (transmitter) readily usable for control and optimization.

Although optimization procedure [2] for B-B equation can possibly be implemented on-line by taking advantage of new state-of-the-art distributed computers, there are prohibitive cost requirements in doing this even for one measurement point.

Muneer [2] computed Thermodynamic properties of steam finding the five constants of B-B Equation through high level optimization programs for a least squares fit. B-B Equation is used to find 3rd property where two are given. The developed constants are good up to: .8 times of critical density, 20 mpa pressure, and 1300°C. A complicated off-line optimization is used with 72 data points. In this method it was suggested that, the initial values must carefully be selected for convergence. Error check was made for pressure determination only at 400°C when density is given. It was found that the error is great for finding temperature and specific volume.

However, pressure and temperature can be measured easily and the most important is to determine the density. Furthermore, B-B Equation developed through an otpimization procedure has large errors, as the temperature and pressure varied [3]. Also, only steam properties are worked out which means more equations are needed for other substances.

So, a practical way is desired as described below. Furthermore, the proposed method can determine the enthalpy and entropy as well, which is not provided by B-B Equation. Other equations are required for such properties. Enthalpy and entropy are essential properties in finding turbine efficiency for power plant steam balance and in implementing cogeneration optimization.

Knowing the fact that the tables are used to find the properties of fluid from measured pressure and temperature values, the information of tables is entered in a functional relation which are imbedded into distributed processors.

The measured values of temperature and pressure from transmitters are entered into microprocessors which contain equations in function block forms to determine the other properties. The accuracy is provided by using the correction values which are produced by the functional relations based on measured temperature and pressure [4]. The accuracy is controlled by the proper assignment of range for functional relations. In case of wide operational conditions, the ranges for functional relations can still be made small by dividing the total range into smaller segments and by increasing the number of functional relations to cover the total range. In this way, the desired accuracy is provided in a flexible way.

Furthermore, the heat flow through a conduit is also determined on-line by the additional measurement of differential pressure (ΔP) and using the standard flow relations along with the properties already determined [4].

Such methods are readily implemented by simple function blocks which are resident in microprocessor firmware in machine language. The current distributed processors provide sampled measurements 4 times per second as standard and as often as 50 times per second if needed.

The method has been tried on steam with a pressure range of 4000-6000 kpa, temperature range of 350-450°C. The results indicated that the accuracy was less than .01% in most cases and slightly higher in few occasions. This was done by dividing the region into four subregions. A method for further improving the accuracy is also described.

2. Description of Method

For practical applications, the fluid is assumed to be in vapor state (usually superheated); the temperature and pressure is known as easily measured by transmitters. Furthermore, the operational values, although vary, still remain within a region of reference design.

2.1 Functional Relation

Now consider reference values of thermodynamic properties by subscript "0". Then for thermodynamic properties we assume that density is described in the form [4].

$$\rho = \rho_0 (CF)_T (CF)_P \qquad (1)$$

where,

ρ = density
$(CF)_T;(CF)_P$ = correction factors for T and P
T = temperature
P = pressure

Also, the correction factors are assumed as,

$$(CF)_T = \rho(T, P_0)/\rho_0 \qquad (2)$$

$$(CF)_P = \rho(T_0, P)/\rho_0 \qquad (3)$$

where,

$\rho(T,P_0)$ = density values when T varies and $P = P_0$
$\rho(T_0,P)$ = density values when P varies and $T = T_0$

and readily available in functional relations (curves). Also, note that $(CF)_T$ and $(CF)_P$ values are unity for $P = P_0$ and $T = T_0$ (reference values) and in virtue of Equation (1) the density is $\rho = \rho_0$. The values of $(CF)_T$ and $(CF)_P$ are obtainable through fluid property tables [5]. The enthalpy and entropy values are also determined in real-time by the same method and not repeated.

2.2 Improvement of Accuracy

The assumed form generates an error when both P and T varies. The range of P and T are selected to keep the error within desired margin. However, if the operating range is large we have to divide the total region into subregions and utilize the proper subregion for calculations. The details will be shown in the section of implementation.

The accuracy is further improved by a modified form of Equation (1), which may be named as "dynamic correction" method.

$$\rho = \rho_0 [(CF)_T (CF)_P]^n \qquad (4)$$

where, n is a function of T and P,

$$n = f(P,T) \qquad (5)$$

The n value is also calculated in real-time by using the measurements of P and T. The functional relation f is developed. Beforehand, for a given fluid, the various values of n are tried for different P and T values and the minimum error between table values and calculated values are noted. Such n values and corresponding P and T values made up the Equation (5). In determining the function, a curve fitting procedure is used. Experimenting for steam properties, it was found that the n values to provide the desired accuracy can be provided when n is function of T only,

$$n = f_T(T) \qquad (6)$$

as it is utilized in implementing the procedure for steam.

3. Implementation

3.1 Single Region Processing

The implementation of finding ρ value from T and P measurements are shown in Figure 1 for a single region of operation.

3.2 Multiple Subregion Processing

For the multiple subregions the method of implementation will be described by an example. Consider an operating region of steam of boundaries between 350-450°C and 4000-6000 kpa. Assume that the region is to be divided into 4 equal subregions numbered 1-4, as shown in Figure 2. Density of fluid will be calculated since it has the most tendency to produce error. Enthalpy and entropy is less sensitive to variations.

Consider "Region 1" in Figure 2. The correction factors of Equations (2) and (3) are shown in Figures 3 and 4 respectively. The functional relations of correction factors are represented by function blocks to determine the value of ρ for temperature and pressure falling in Subregion 1 which is about the reference values of P_0^1 = 4500 kpa and $T_0^{\prime}$ = 375°C.

Consider the correction factors for Subregion 1 as $(CF)_T^1$ and $(CF)_P^1$ for temperature and pressure respectively. The same can be written for other subregions 2-4 as well, designated by proper superscripts. Note that the temperature correction factors for Subregion 1 and 2 are shown in Figure 5 along with temperature logic blocks f_T', f_T''. The corresponding logic blocks for pressure are f_P' and f_P'' covering the pressure Subregions 4000-5000 kpa and 5000-6000 kpa respectively.

Figure 6 describes the logic diagram for finding the value. The subregion logic contains four logic blocks: two for temperature as shown in Figure 5(a) and two for pressure as shown in Figure 5(b). Only one of the outputs of SR is the one which corresponds to the proper subregion where temperature and pressure belongs, while the other SR values are zero. Next, SR signals enter into the temperature correction logic which contains temperature correction factor function blocks as in Figure 3. They are arranged with SR signals so that the appropriate value of temperature correction factor $(CF)_T$ outputted based on the measured temperature entering into the logic. The pressure correction factor $(CF)_P$ is found similarly. Also, one of the density reference value is outputed from reference logic block based on the SR values or the subregion of operation. Then, when these three output signals are multiplied (Equation (1)), the density signal is obtained. The details of logic blocks in Figure 6 are not given.

3.3 Improvement of Accuracy

The accuracy of measurement is greatly improved by using the Equation (4) instead of Equation (1) in Figure 1. However, the details of providing the n value for Equation (4) and implementing it is quite similar to what has been demonstrated, and the details will not be given.

4. Results and Conclusion

It has been shown that the measurements of thermodynamic properties are possible through smart transmitters having microprocessor-based function blocks. The accuracy can be controlled based on what is desired. Considering steam, a maximum error within .01% is easily obtained for a measurement range of 50°C temerature and 1 mpa pressure. It makes no difference as how wide the range of temperature and pressure may be, as the same range of measurement can be kept by assigning multiple regions. The method of dealing with multiple regions are described. Also, a region can be divided into subregions of smaller range to improve the accuracy, since the error is reduced as the temperature and pressure range decreases.

Furthermore, a special method named as "dynamic correction" is utilized to modify the values of correction factors to reduce the error. Based on this, the maximum error is reduced to 50% to its value with a greater average reduction. That is, an accuracy within .005% of the measurement is obtained routinely and such accuracy can further be improved without prohibitive costs.

If the swings of process variables are not great. The cost of hardware is reduced. However, any wide swing in process variable is not detrimental to accuracy, it may just contribute to cost. The point to be made is that the logic blocks perform their functions four cycles per second, and such frequency can be increased with no difficulty. Therefore, the method provides a greater accuracy and flexibility similar to a digital device and the responsiveness as an analog transmitter. These two desired features can only be combined by the method proposed in this paper.

4. References

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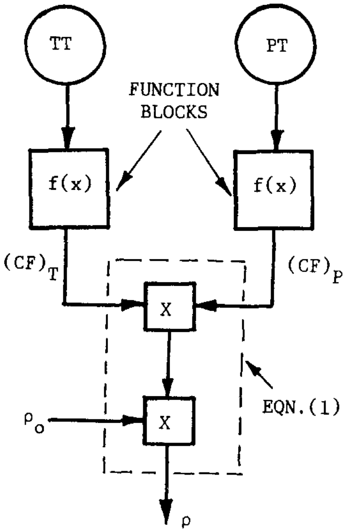

FIG. 1 FUNCTION BLOCK DIAGRAM TO FIND DENSITY

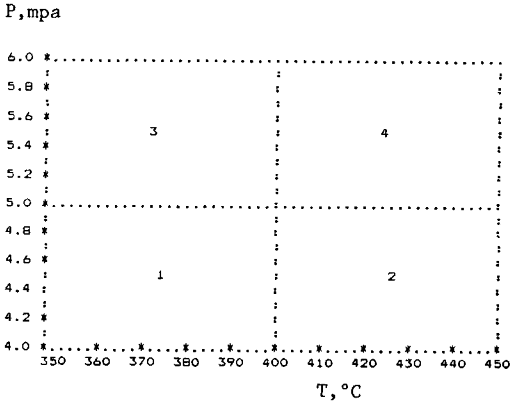

FIG. 2 SUBREGIONS FOR IMPROVED ACCURACY

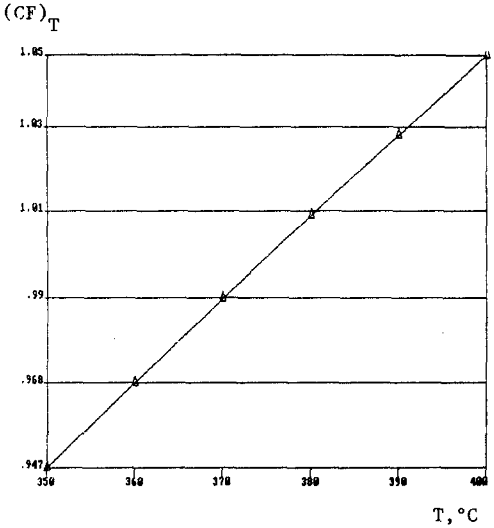

FIG. 3 TEMPERATURE CORRECTION FACTOR, (P_o = 4.5 mpa)

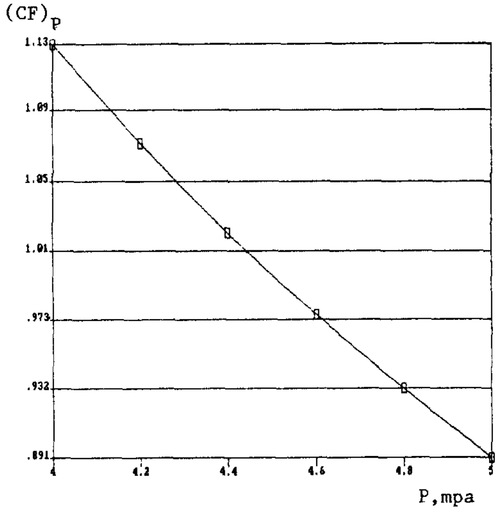

FIG. 4 PRESSURE CORRECTION FACTOR (T_o = 375°C)

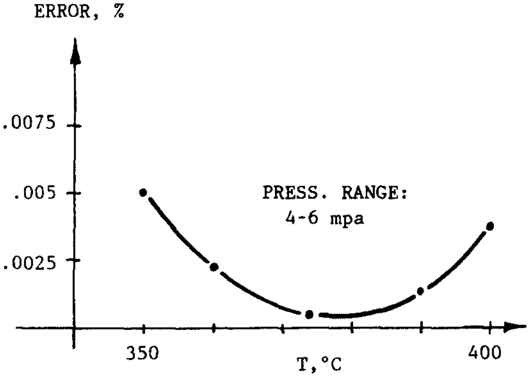

FIG. 7 IMPROVED ACCURACY BY DYNAMIC CORRECTION FACTOR

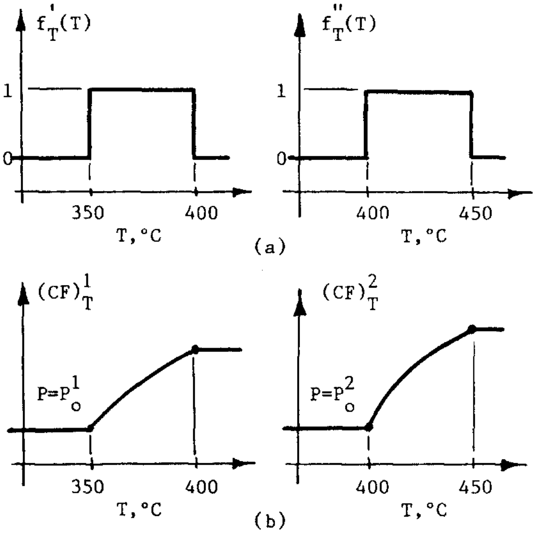

FIG. 5 LOGIC BLOCKS (a), AND TEMPERATURE CORRECTION FACTORS (b), FOR SUBREGIONS

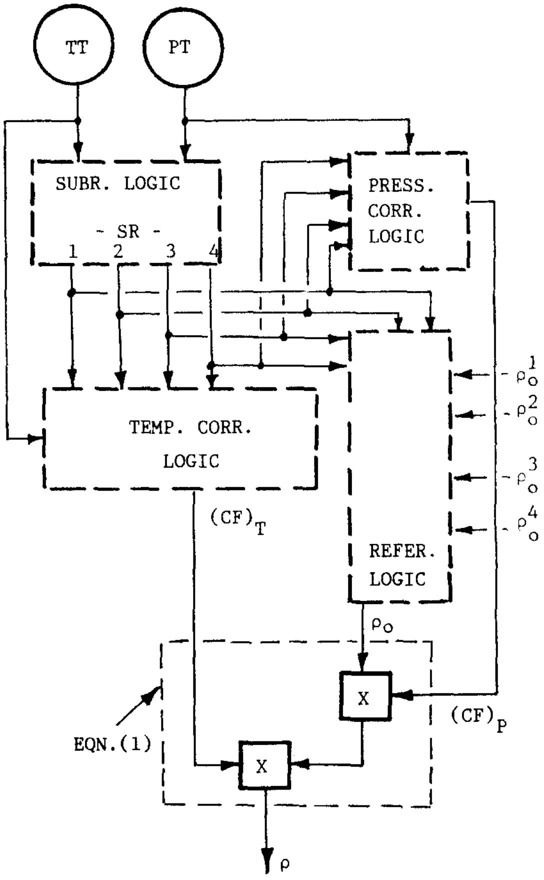

FIG. 6 DENSITY LOGIC DIAGRAM FOR MULTIPLE SUBREGIONS