CHEMICAL ENGINEERING TRANSACTIONS
VOL. 46, 2015
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet
Guest Editors: Peiyu Ren, Yancang Li, Huiping Song

**ISBN** 978-88-95608-37-2; **ISSN** 2283-9216
DOI: 10.3303/CET1546167

# Study on the Reconstruction of 3D Temperature Field in Furnaces Based on Visual C++6.0 and OpenGL

Yuxia Li*, Yuanfang Cai, Wei Fang

Department of Energy and Power Engineering, Faculty of Water Resources and Hydroelectric Engineering, Xi'an University of Technology, Xi'an, China 710048.
li-yuxia@163.com

Monitoring the combustion in boiler furnaces is significant for the safety production and a higher production efficiency of thermal power plants. Based on ultrasonic pyrometry, an algorithm is proposed to reconstruct 3D temperature field of furnace flame in this paper. Meanwhile according to characteristics of discrete temperature points, a method for tracing isotherms and isothermal surfaces in temperature field is also designed. In Visual C++6.0 and OpenGL environment, a program is developed to reconstruct the temperature field.

## 1. Introduction

The combustion of pulverized coal in furnace is not only associated with the safety production of thermal power plants, but exerts an influence upon its production efficiency (CHANG, WANG, & HUANG, 2006). Via monitoring the combustion of pulverized coal, the flame combustion status can be reflected in time, and once a boiler operates at off-design conditions, timely adjustments or relevant emergency measures for combustion can be made by operating personnel (Donaldson et al., 2005).

The large size of coal-fired boilers in power plants, poor operation condition and high flame temperature in furnaces make it unsuitable for contact temperature measurement (Baker, 1998; Stephenson, 1993) and some other non-contact temperature measurement, optical temperature measurement (Wickersheim, 1984) for instance, to measure the temperature in furnaces. In recent years, extensive attention has been exercised upon the acoustic pyrometry, which leads to a rapid development. However, the temperature field of thermal power plants constructed by acoustic pyrometry are mainly 2D temperature field (Jia, Gao, & Lu, 2013; Lu, Sun, & Li, 2012), and there is few study on the reconstruction of 3D temperature field by using pyrometry (Lu et al., 2012; ZHOU, WANG, MIAO, & WU, 2013).

In this paper, flame temperature of discrete monitoring points in furnaces is acquired by means of acoustic pyrometry. Then, in Visual C++6.0 and OpenGL environment (YU & JIAO, 2011), a method for tracing isotherms and isothermal surfaces in 3D temperature field is examined, and a program is developed to reconstruct the temperature field of furnace flame. Finally, satisfactory results are obtained.

## 2. Data acquisition system for furnace temperature

In thermal power plants, the cross sections of tangentially fired furnaces are roughly squares. To acquire the flame temperature in furnaces, ultrasonic sensors are placed at regular intervals on every edge of furnaces and there are totally eight ultrasonic receiver-transmitters in each layer, as shown in figure 1. As the same placement, sensors are installed in different three cross sections of a furnace.

Propagation velocity of ultrasonic wave varies from medium to medium at different temperatures. By measuring time interval between transmitting and receiving ultrasonic wave, the system can achieve the wave's propagation time. Furthermore, if we know the distance between different sensors, propagation velocity of ultrasonic wave can be calculated, and the gas temperature can therefore be acquired in accordance with acoustic pyrometry (SHEN, WU, AN, LI, & JIANG, 2007).

Please cite this article as: Li Y.X., Cai Y.F., Fang W., 2015, Study on the reconstruction of 3d temperature field in furnaces based on visual c++6.0 and opengl, Chemical Engineering Transactions, 46, 997-1002 DOI:10.3303/CET1546167

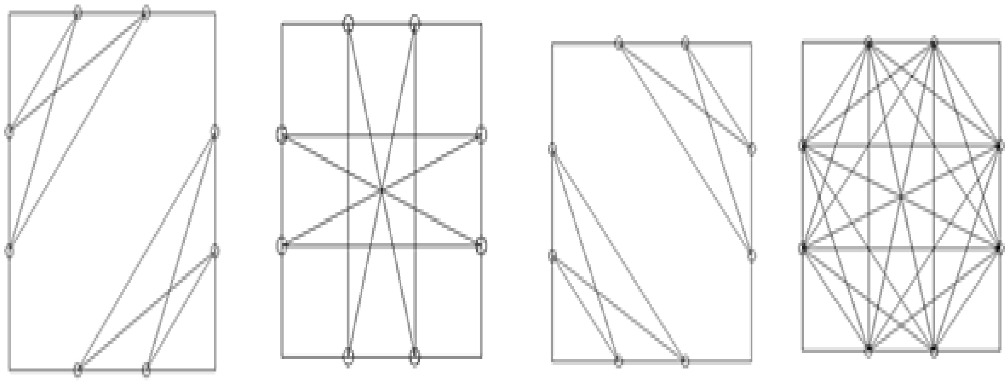

*Figure 1: Placement of ultrasonic sensors distributed in three layers*

## 3. Visualization of 3D temperature field

### 3.1 The mesh of temperature data

After data acquisition and data treatment done by the measurement system equipped with ultrasonic sensors, temperature of discrete monitoring points is obtained. Then, coordinates of these discrete points are meshed by triangles, and a triangle mesh is generated in order to calculate temperature of every point in the furnace, trace isotherms and plot isothermal surfaces.

In 3D temperature field, there is a regular tetrahedron containing discrete monitoring points. All monitoring points are introduced into the established regular tetrahedron. On the basis of Delaunay triangulation (SHEN, WU, AN, LI, & JIANG, 2007). Temperature points are inserted into the tetrahedron point by point, and the chain table of new points is updated continuously. It is noteworthy that new points has to satisfy the following two requirements, i.e. any triangular mesh composed of arbitrary four points should be unique, and any four points consisting of a triangular mesh cannot be on one circle; thorough the replacement of diagonal lines, interior angle of the minimum angle in a convex quadrangle made up of arbitrary four points no longer increases. The detailed process is shown in figure 2.

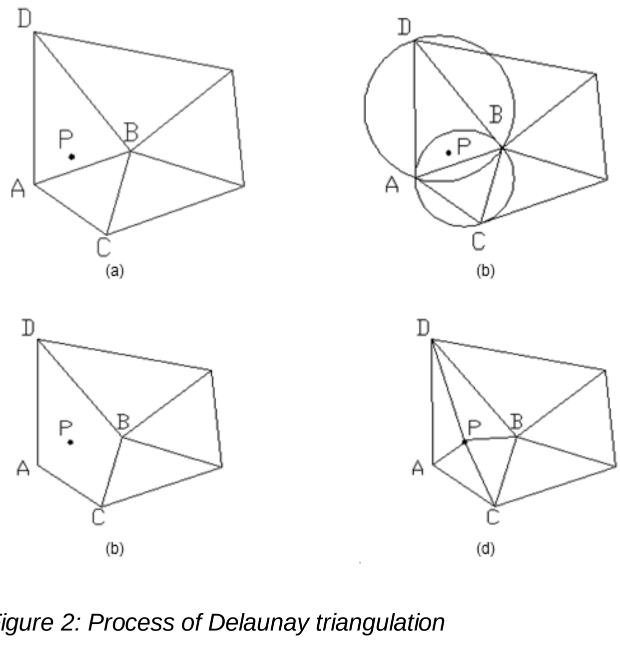


*Figure 2: Process of Delaunay triangulation*

In figure 2(a), point P is inserted into the triangular mesh preliminarily formulated by discrete monitoring points. Then, point P is tested whether it follows Delaunay triangulation, namely whether it obeys the empty circumscribing sphere criterion and the minimum interior angle maximized criterion, as shown in figure 2(b). If point P does not conform to criteria mentioned above, delete it and find another point which can follow Delaunay triangulation. Otherwise, the program keeps running. After verifying the correctness of point P, the common

edge AB between triangle ABD and ABC can be deleted, as indicated in figure 2(c). In figure 2(d), point P is connected with the surrounding temperature points, and a new triangular mesh is generated.
In establishing a new triangular mesh, repeatedly executive the four steps outlined above until no more point satisfying Delaunay triangulation is discovered.
According the algorithm formulated above, triangulation of discrete temperature points is simulated by using MATLAB, and 64 meshes are acquired. The result shown in figure 3 indicates that the proposed algorithm can triangulate discrete temperature points in space.

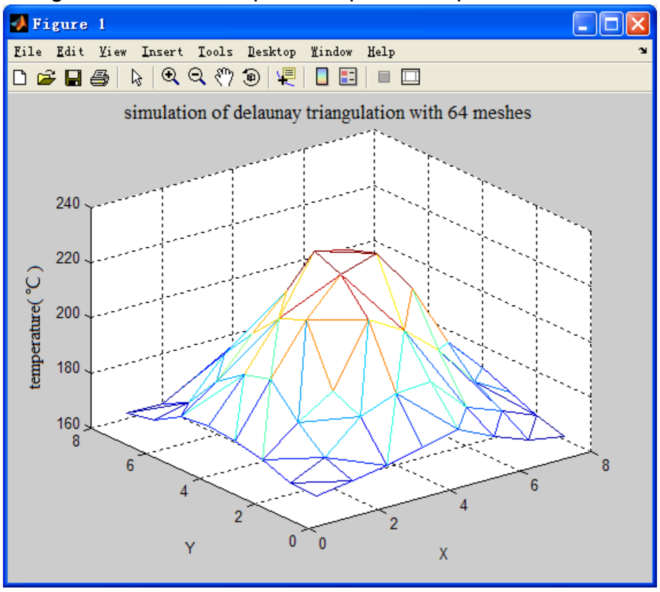


*Figure 3: Simulation result of triangulation*

### 3.2 Tracing isotherms and isothermal surfaces

In fact, plotting an isotherm is to sequentially connect different isothermal points among massive discrete temperature points, the difficulty of which is how to find out these isothermal points. To obtain isotherms, the following two problems have to be solves:
(1) Locating isothermal points
When a triangular mesh is formulated, the coordinate of an isothermal point can be calculated with the help of its surrounding points whose coordinates have already been known. In this paper, we use linear interpolation (Milanese, Norton, Piet-Lahanier, & Walter, 2013) to obtain coordinates of temperature points in furnaces.
Suppose that there is a line segment represented by L. The endpoints of L are M and N, and their temperature is respectively $t_M$ and $t_N$. If the temperature of an interpolation point is $t$ and $t$ satisfies $t_M<t<t_N$ or $t_N<t<t_M$, coordinates of the interpolation point can be calculated as follows:

$$X = x_M + \left(\frac{t_M - t}{t_M - t_N}\right)(x_M - x_N) \tag{2-1}$$

$$Y = y_M + \left(\frac{t_M - t}{t_M - t_N}\right)(y_M - y_N) \tag{2-2}$$

$$Z = z_M + \left(\frac{t_M - t}{t_M - t_N}\right)(z_M - z_N) \tag{2-3}$$

(2) Plotting isotherms
After acquiring coordinates of interpolation points, connect isothermal points in sequence and isotherms are plotted. Based on unique properties of triangle and tetrahedron, an algorithm is presented to trace isotherms in this paper, and simulation is then carried out.
In a triangular mesh, there are only four temperature distributions, i.e. temperature of interpolation points is higher than that of all three vertices of a triangular mesh; temperature of interpolation points is lower than that of all three vertices; temperature of interpolation points is higher than that of only one vertex; temperature of interpolation points is higher than that of two vertices. Four temperature distributions are shown in figure 4 respectively.

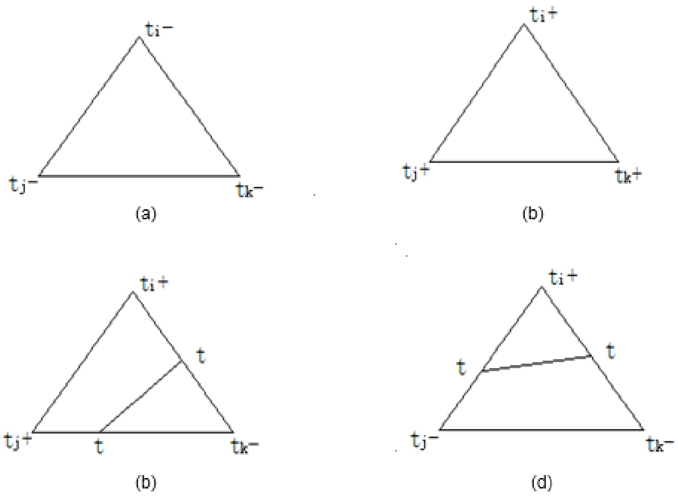


*Figure 4: Sketch map of tracing isotherms*

Suppose that three vertices in part of a triangular mesh are represented by i, j and k. In the figure, ‘+’ means that temperature of a vertex is higher than temperature *t* of interpolation points; otherwise, ‘-’ will take the place of ‘+’. The following conclusions can be drawn from above four situations:

Because temperature of all vertices is higher or lower than that of interpolation points in figure 4(a) and (b), namely: $t<\{t_i, t_j, t_k\}$ or $t>\{t_i, t_j, t_k\}$, there is no interpolation point in three edges of a triangular mesh, and the isotherm does not exist in such mesh. While temperature of interpolation points falls among that of three vertices, two situations may occur as shown in figure 4(c) and (d) and there must be interpolation points in two edges of a triangular mesh. Therefore, an isotherm can be plotted by connecting these two interpolation points.

After setting a fixed displaying density in MATLAB program, a simulation of plotting isotherms is conducted by applying the preceding algorithm. Simulation results are shown in figure 5.

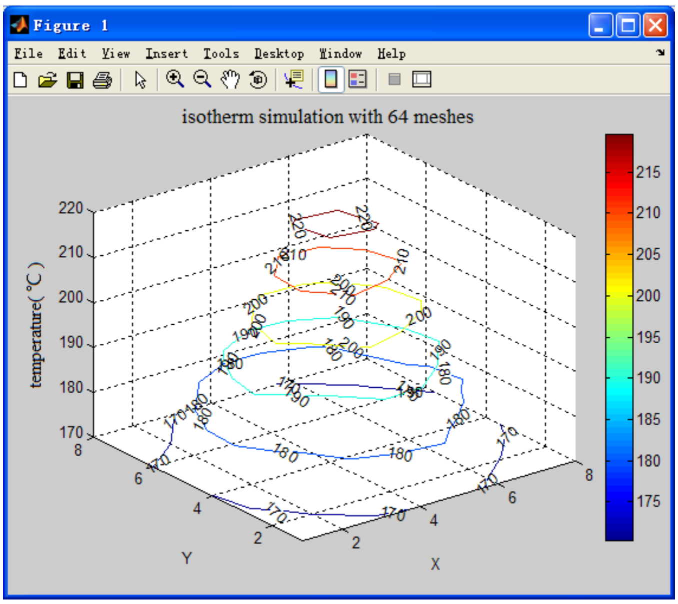


*Figure 5: Simulation of plotting isotherms*

(3) Plotting isothermal surfaces

Take a regular tetrahedron micro-unit for example and suppose that vertices of the tetrahedron are respectively i, j, k and l. ‘+’ means that temperature of an vertex is higher than temperature t of interpolation points; otherwise, ‘-’ will take the place of ‘+’.

On the basis of the algorithm for plotting isotherms, a method is discussed to trace isothermal surfaces in two different conditions:

If temperature $t$ of interpolation points is higher or low than temperature of all vertices, namely: max($t_i$, $t_j$, $t_k$, $t_l$) ≤ $t$ or min($t_i$, $t_j$, $t_k$, $t_l$) ≥ $t$, we cannot obtain any interpolation point in arbitrary edge as well as any isotherm, and therefore there is no isothermal surface. Only when temperature of interpolation points lies among that of vertices, namely: min ($t_i$, $t_j$, $t_k$, $t_l$) < $t$ < max ($t_i$, $t_j$, $t_k$, $t_l$), can we expect to acquire an isothermal surface.

### 3.3 Coloration of temperature field and program design

In this paper, an algorithm for rendering temperature field is presented on the basis of OpenGL in which the color is quantified by RGB value.

Suppose that the average temperature of a rendered triangular micro-unit is $T_{aver}$, and $T_1$, $T_2$ and $T_3$ are the temperature of three vertices in the micro-unit. In 3D temperature field, if the average of actual temperature is $T_{temp}$, the maximum of actual temperature is $T_{max}$, and the minimum of actual temperature is $T_{min}$, then,

$$T_{aver} = \frac{T_1 + T_2 + T_3}{3} \tag{2-4}$$

$$T_{temp} = \frac{T_{\max} + T_{\min}}{2} \tag{2-5}$$

The flowing three situations can be discussed:

(1) If $T_{aver} > T_{temp}$, the red value is $R = \frac{T_{aver} - T_{temp}}{T_{temp} - T_{\min}}$ and the blue value is $B = 0$.

(2) If $T_{aver} < T_{temp}$, the blue value is $B = \frac{T_{temp} - T_{aver}}{T_{temp} - T_{\min}}$, and the red value is $R = 0$.

(3) All green values are calculated by:

$$G = \frac{1 - \left| T_{temp} - T_{aver} \right|}{T_{temp} - T_{\min}}$$

An executive file named WDCCJ.exe is achieved after compiling and running the program. The result is shown in figure 6.

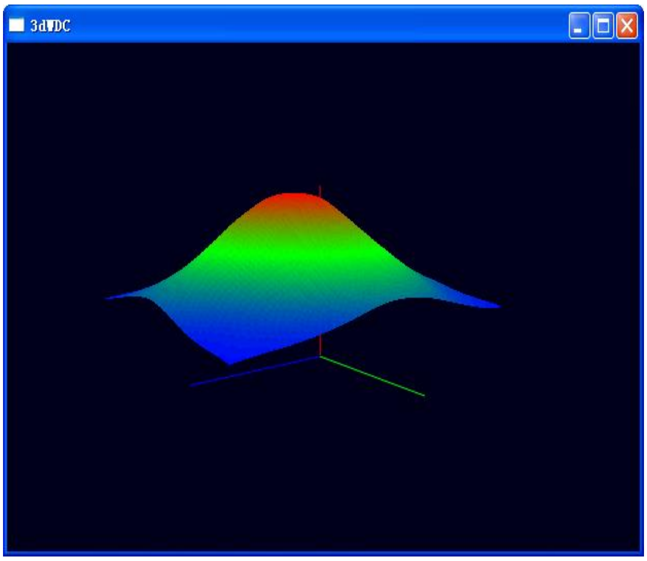

*Figure 6: Result of the rendering program*

## 4. Conclusions

In Visual C++6.0 and OpenGL environment, an algorithm is presented to reconstruct 3D temperature field of furnace flame in thermal power plants. According to the algorithm, a program for reconstruction of the temperature field is also developed and satisfactory results are obtained. The proposed algorithm provides a new solution to reconstructing the temperature field of furnace flame. The developed program can be transplanted into various systems after related compilation, and possesses favorable performance on real-time and stability.

**References**


Baker, B. (1998). Precision Temperature Sensing with RTD Circuits. *AN687, Microchip Technology Inc*.

Chang, R. I., Wang, F., & Huang, Q. X. (2006). Study on the flame monitoring and combustion diagnosis control optimizing inside pulverized coal boiler of power plant. *Energy Engineering, 4*, 003.

Donaldson, K., Tran, L., Jimenez, L. A., Duffin, R., Newby, D. E., Mills, N., Stone, V. (2005). Combustion-derived nanoparticles: a review of their toxicology following inhalation exposure. *Particle and fibre toxicology, 2*(1), 10.

Jia, L. N., Gao, Y., & Lu, D. C. (2013). *Two-Dimension Temperature Field Reconstruction in Furnace by Acoustic Method.* Paper presented at the Applied Mechanics and Materials.

Lee, D.-T., & Schachter, B. J. (1980). Two algorithms for constructing a Delaunay triangulation. *International Journal of Computer & Information Sciences, 9*(3), 219-242.

Lu, H. B., Sun, W. H., & Li, Z. H. (2012). *Research on Reconstruction Algorithm of Temperature Field by Acoustic Measurement in Boiler.* Paper presented at the Advanced Materials Research.

Milanese, M., Norton, J., Piet-Lahanier, H., & Walter, É. (2013). *Bounding approaches to system identification*: Springer Science & Business Media.

Muzio, L., Eskinazi, D., & Green, S. (1989). Acoustic pyrometry. New boiler diagnostic tool. *Power Engineering, 93*(11), 49-52.

Shen, G. Q., Wu, Z. Q., An, L. S., Li, K., & Jiang, G. S. (2007). Reconstruction of Temperature Fields of Furnace on the Basis of Few Acoustic Data [J]. *Journal of Power Engineering, 5*, 012.

Stephenson, D. (1993). Tool-work thermocouple temperature measurements—theory and implementation issues. *Journal of Manufacturing Science and Engineering, 115*(4), 432-437.

Wickersheim, K. A. (1984). Optical temperature measurement technique utilizing phosphors: Google Patents.

Yu, M., & Jiao, S. H. (2011). Application of 3D ship model visualization based on VC++ and OpenGL [J]. *Information Technology, 6*, 048.

Zhou, X., Wang, Q., Miao, Z. N., & Wu, W. G. (2013). Three-dimensional Temperature Field Reconstruction Algorithm Based on RBF Neural Network. *Instrument Technique and Sensor, 5*, 035.