New Base and Burner Design for Utilizing the Compound Gases with Spilled Oil at Using Power Chimney Techniques

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Abstract:

The renewable or non-renewable modern energy kinds have many shapes to utilize power generation. The power chimney tower is one of them developed by low losses, simple and has high facilities that used in spilling oil and/or oil refinery stations and to save clean environment.

In this paper, new base design of power chimney used to increase the utilized energy by increasing the number of burners in addition to introducing new burner design by adding directional vanes. Many parameters influencing the system operation were exactly studied to predict new operation phenomenon. This fundamentally depends the combustion of gases compound the spilled oil. Velocity distribution is the important parameter which gives the first prediction to put the position of erection of power turbine, made or not. The numerical analysis was presented by using GAMBIT and FLUENT 6.3 to predict the high velocity at the expansion of chimney near the Centre of burned gases cover collector. This position is very suitable for promoting and building the power turbine since the velocity was high when the compounded gases is combusted (that there components are the methane gas with other friendly gases and waste). Also, it is concluded that there are high temperature increased by using the new burner design reach (1400-1800) K in comparison with old design without swirlers. It is easy to erect steam or gaseous boiler in contact with furnace for utilizes the heat generated in electrical power generation. So, the other factors, temperature and pressure were studied to coincide with previous papers in this field. The validity of this study was done by comparison to same flow rate of air/fuel ratio of previous study findings to give similar results of parameters.

Keywords: Power, Chimney, Burner, Oil.

تصميم جديد لقاعدة وضرام للاستفادة من الغازات المصاحبة للنفط المستخرج باستخدام تقنية برج القدرة

خلاصة البحث:

هناك عدة انواع واشكال من الطاقات المتجددة وغير المتجددة لتوليد الكهرباء منها. وبرج مدخنة القدرة احد هذه الانواع التي طورت بالمفاقيد القليلة والسهولة والامتيازات الكثيرة لها لتوليد الطاقة من الغازات المصاحبة للنفط المستخرج في العراق وغيره من الطاقات والطرق الواعدة لأستثمار امثل للوقود المتطاير في الهواء وكذلك تخليص البيئة من اثاره السلبية.

في هذا البحث، تمت دراسة العوامل المهمة التي لها تأثيراً مباشراً على عمل منظومة القدرة والتي تعمل بشكل اساسي اعتماداً على حرق الغازات المصاحبة للنفط المستخرج. تم انشاء تصميم جديد لضرام وقاعدة فرن القدرة بإدخال تقنية الدوران المحوري لزيادة كفاءة الاحتراق. تم دراسة عدة عوامل اهمها توزيع السرعة الذي ينبئ أولاً بموقع تنصيب توربين القدرة ومكان تنصيبه. تم تقديم تحليل عددي وباستخدام برنامج الكامبت والفلونت للتنبؤ بمكان أعلى سرعة قرب توسع المدخنة في مركز قاعدة غطاء مجمع الغازات المشتعلة. حيث إن هذا المكان هو الأكثر ملائمة لبناء توربين القدرة ودعمه لكون سرع الهواء قد وصلت إلى مديات عالية عند حرق الغازات المصاحبة للنفط والتي تكون على الاغلب مكونة من غاز الميثان وغازات وشوائب مصاحبة. كذلك استنتجنا زيادة عالية في درجات الحرارة المتولدة عند استعمال التصميم الجديد للضرام والقاعدة لمديات تقرب من ١٤٠٠-١٨٠٠ درجة حرارية مطلقة عند استخدام نفس الوقود ونفس الكمية . ايضاً يمكن الاستفادة من حرارة الفرن بنصب مرجل بخاري او غازي لتوليد الكهرباء. كذلك تمت دراسة العوامل الأخرى المؤثرة على كفاءة المنظومة مثل درجة الحرارة وفرق الضغط وتبين إنها متوافقة لما تم دراسته سابقاً من قبل الباحثين في أدبيات الموضوع. و للتحقق من صحة الدراسة تمت المقارنة مع نتائج دراسة سابقة باستخدام نسب مماثلة للهواء/الوقود وتبين الحصول على قيم مقاربة لعوامل الدراسة المختلفة.

1- Introduction:

Power chimney technology is a promising large scale of power generation. This technology was first described by Gȗnter in 1931 and tested with the 50 kW Manzanares prototype plant since 1980 [1]. There are four components for the combination of this prototype: combustion chamber, chimney, turbine connected with electrical generator.

The installation of power chimney at locations near the oil spilling stations for utilizing of compound gases which burned in this suggested power plant.

Haaf *et al.* [2], Haaf [3] and Schlaich [4] described the operation and presented results for a prototype solar chimney power plant built in Manzanares, Spain in 1982.

Sislian et.al. (1988) [5] measured experimentally many mechanical parameters in combustor and concluded that turbulence in the jet diffusion flame was appreciably more anisotropic than in the corresponding cold jet in all regions of the flow. Gaseous fuels are usually characterized by clean combustion, with low rates of soot and nitric oxides. The main problem is that of achieving the optimal level of mixing in the combustion zone.

A mixing rate that is too high produces narrow stability limits, but a mixing rate that is too low may make the system prone to combustion-induced pressure oscillations. Many different methods have been used to inject gas into conventional combustion chambers, including plain orifices, slot, swirlers, and venture nozzles [6]. Backstrom and Fluri [7] developed two analyses for finding the optimal ratio of turbine pressure drop to available pressure drop in a chimney power plant to be 2/3 for maximum fluid power and using the power law model for this prediction.

Pretorius and Kröger [8] evaluated the influence of a recently developed convective heat transfer equation, more accurate turbine inlet loss coefficient, the performance of a large scale chimney power plant. This simulation of study concluded that the new heat transfer equation reduce the annual plant power output by 11.7%, but , the more realistic turbine inlet loss coefficient only accounts for a 0.66˚rise in annual power production.

Ninic and Nizetic [9] developed and used the availability of warm, humid air via the formation of up draft “gravitational vortex column” situated over turbine with numerical solution for chimney power plant.

The compound gases pass through burner vents which circumstances with air vent to create high mixing rate to combust inside the cub of combustion chamber. The air near the ground absorbs the heat to decrease its density. The hot air particles move up to hit the cub ceiling continuously and go to chimney vent. This series heating generates continuous movement of air, then, produces electrical energy by installing turbine connected to electrical generator. The height of chimney causes high pressure difference between the upper and lower points. This pushes increasingly the movement of air particles between the lower points of chimney to up. In addition, the power may be generated by connecting gas or steam turbine to use the resulting hot gases before chimney inlet vent [10].

Love et.al. (2009) [11] developed an experimental method for the rapid characterization of combustion properties, and measured the amounts of NOx and combustion products. Azazi (2001)[12] presented a study to Hartha power plant furnace in Iraq, used a two dimensional aerodynamics and thermal aspects by using FORTRAN computer programme. He concluded that 1500 ºC inside temperature of furnace and the tangential velocity played a great role for keeping the stability of the fire ball. Alhabbubi (2002) [13] presented a prediction of temperature distribution and heat flux along the walls of Al-Mussaib thermal power plant furnace in Iraq by using zonal method to analyze the radiative heat transfer. He found that the temperature range from 1450K to 2100 K. Sobolev et.al. (2008)[14] presented a numerical calculation results of methane turbulent diffusion jet flames of rectilinear-swirl burner in the furnace of high capacity boiler by using CFD AnsysCFX10.0 programme. Hannun (2009) [15] studied the combustion of liquid and gaseous fuel in Nassiriya power plant furnace, analyzed numerically the mechanical properties by using FLUENT code. Hannun et.al. (2011) [16] presented a prediction for mechanical parameters influenced the operation of solar power chimney at Nassiriya city. Hannun (2011) [10] predicted the parameters inside the combustion chamber of power chimney by using similar eight burners consist of vents for air and fuel without swirlers.

The aim of study is to redesigning a burner and number of burners of furnace base to reach high efficient combustion during utilizing the compound gases at oil refinery stations.

2-Numerical model

2-1 Physical model

In this study, practical prototype logically depended on as shown in Fig. 1 is selected as a physical model for simulation. The chimney height is 50 m and radius 1 m, the frustum (cup) of 15 m radius at the base and 10m height. There are four burners arranged around the chimney Centre to ensure continuous, efficient flame stability. Each burner consists of five central cylindrical vents (each 0.2m radius) for entering gaseous fuel, the outer vents (the inner radius 1m and the outer 2m) designed as separated inclined swirler vents for flowing of air with high turbulent mixing rate with fuel to ensure perfect combustion inside the chamber. The vanes of one burner are designed to swirl air in a direction reversed to that of neighbor burner to prevent the friction among mixture (fuel and air) particles [15, 19].

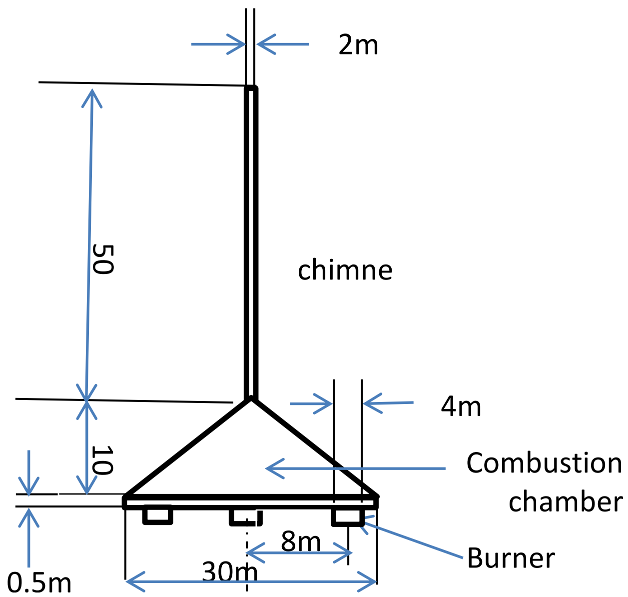


Fig.1 Physical Prototype

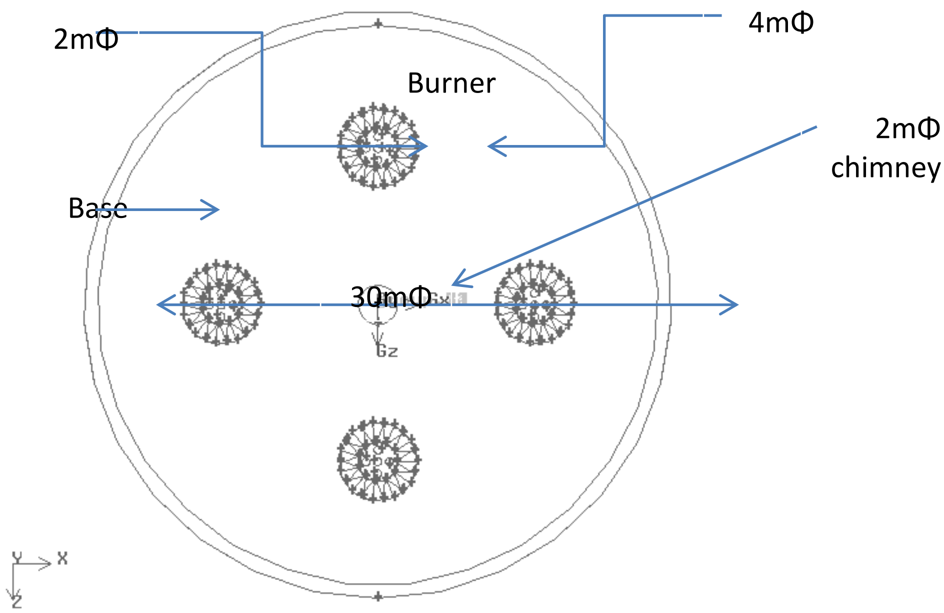


Fig.2 Base and Burners of Prototype

2-2 Mathematical model

There are many prototypes in the world have large different heights of chimney up to 500 m, with different radii. The designs of combustion chamber have many shapes and different dimensions. The design mentioned in previous paragraph (2-1) is considered as model to be analyzed.

The continuity, Navier – Stokes, energy equations and k-ε equation are shown below [5]:

$$\frac{\partial \rho}{\partial t}+\frac{\partial (\rho u)}{\partial x}+\frac{\partial (\rho v)}{\partial y}=0 \tag{1}$$

$$\frac{\partial (\rho u)}{\partial t}+\frac{\partial (\rho uu)}{\partial x}+\frac{\partial (\rho vu)}{\partial y}=\rho g\beta(T-T_{\infty})+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right) \tag{2}$$

$$\frac{\partial (\rho v)}{\partial t}+\frac{\partial (\rho uv)}{\partial x}+\frac{\partial (\rho vv)}{\partial y}=-\frac{\partial p}{\partial y}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right) \tag{3}$$

$$\frac{\partial (\rho cT)}{\partial t}+\frac{\partial (\rho cuT)}{\partial x}+\frac{\partial (\rho cvT)}{\partial y}=\lambda\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right) \tag{4}$$

$$\frac{\partial}{\partial t}(\rho K)+\frac{\partial}{\partial x_i}(\rho K u_i)=\frac{\partial}{\partial x_j}\left(\left(\mu+\frac{\mu_t}{\sigma_K}\right)\frac{\partial K}{\partial x_j}\right)+G_K+G_b-\rho\varepsilon+S_K \tag{5}$$

$$\frac{\partial}{\partial t}(\rho\varepsilon)+\frac{\partial}{\partial x_j}(\rho\varepsilon u_i)=\frac{\partial}{\partial x_j}\left(\left(\mu+\frac{\mu_t}{\sigma_K}\right)\frac{\partial\varepsilon}{\partial x_j}\right)+C_{i\varepsilon}(G_K+C_{3\varepsilon}G_b)-C_{2\varepsilon}\rho\frac{\varepsilon^2}{K}+S_\varepsilon \qquad (6)$$

Where:

C_1	C_2	C_μ	$\sigma_{k,t}$	$\sigma_{\varepsilon,t}$	σ_c	k	ε
1.44	1.92	0.09	1	1.3	0.7	0.4	0.9

2-3 Boundary conditions:

1. For chimney

$$\frac{\partial T}{\partial x}=0\,,u=0\,,v=0 \qquad (7)$$

For the base inside the combustion chamber

$$\frac{\partial T}{\partial y}=0\,,u_d=0,v_d=0 \qquad (8)$$

For outlet conditions:

At x= ± ∞, T = constant=300K, P = $P_{atmosphere}$ (9)

2. Symmetrical axis at chimney centre axis, i.e:

$$u_{(x=+x)}=u_{(x=-x)}\,,v_{(x=+x)}=v_{(x=-x)},p_{(x=+x)}=p_{(x=-x)} \qquad (10)$$

$$\mu_m\left(\frac{\partial u_d}{\partial y}+\frac{\partial v_d}{\partial x}\right)_{(x=+x)}=\mu_m\left(\frac{\partial u_d}{\partial y}+\frac{\partial v_d}{\partial x}\right)_{(x=-x)} \qquad (11)$$

The gaseous fuel was natural gas with high ratio of methane which burns according to the following chemical reaction (complete combustion):

$$CH4+2O2 \longrightarrow CO2+2H2O \qquad (12)$$

The molecular weight of carbon (C), hydrogen (H) and oxygen (O) are 12, 2 and 32 respectively. Therefore, the combustion of one mole of methane with two moles of oxygen produce one mole of carbon dioxide with two moles of water, that means one kg of methane with four kg of oxygen to produce the following:

$$M_{H_2O} = m_{CH_4} \times \frac{W_{H_2O}}{W_{CH_4}} \tag{13}$$

$$M_{CO_2} = m_{CH_4} \times \frac{W_{CO_2}}{W_{CH_4}} \tag{14}$$

Therefore, the fuel burning inside the chimney chamber follows the equation:

Heat released by burning fuel= Heat absorbed by air +Heat radiated to all inside faces of the chamber

$$Q = m_a c_p (T_f - T_a) + \acute{\varepsilon} \sigma A_p (T_f^4 - T_w^4) \tag{15}$$

Where Q (kW) = mass flow rate × calorific value of fuel

2-4 Numerical analysis:

The turbulent flow of mixture (air and fuel) before and after the combustion process inside the system would be analyzed by standard k-ε model. The SIMPLE algorithm with QUICK Scheme method used to solve the pressure –velocity coupling, momentum and energy equations respectively. These methods were explained by many references such as Ref.[17]. So, the Gambit and Fluent Codes are used to describe the results of this paper. Fig.3, 4 and 6 the study case of new burner design and chimney system as designed by GAMBIT.

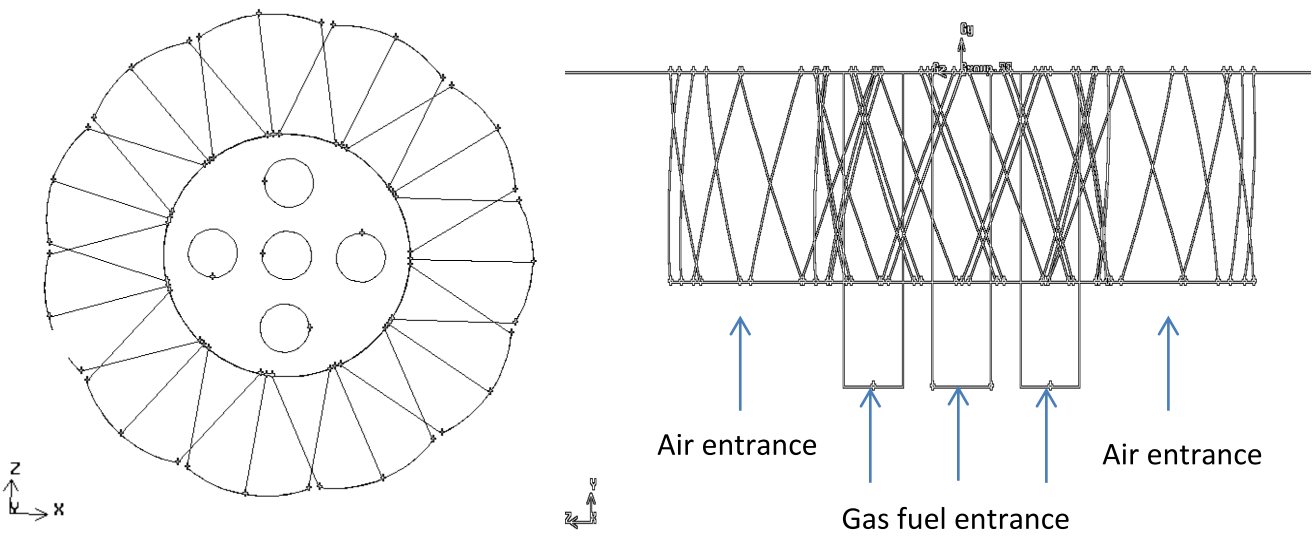


Fig. 3 Front and side view of burner as designed by GAMBIT

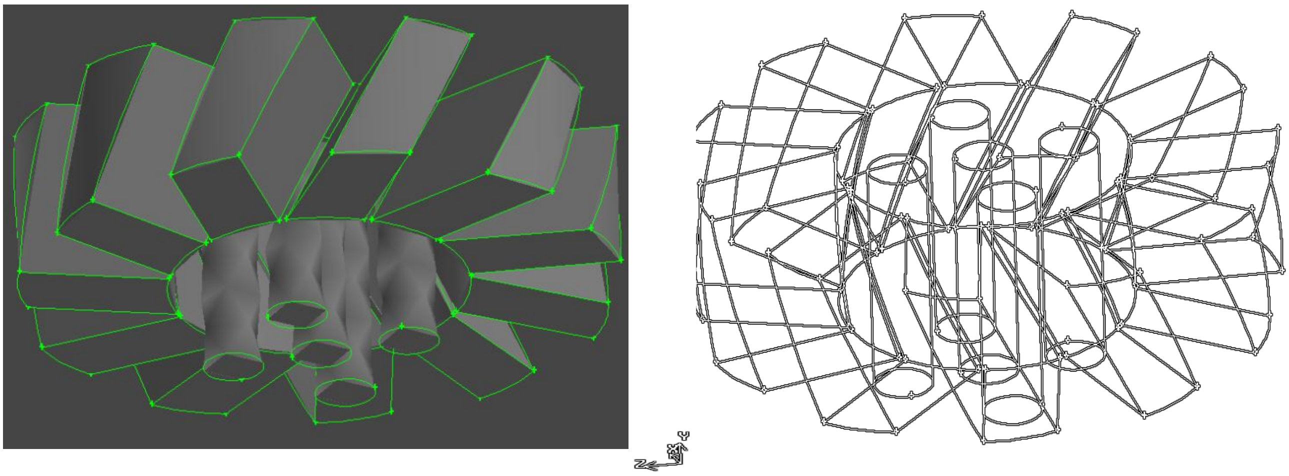


Fig.4 Geometry of burner as designed by GAMBIT

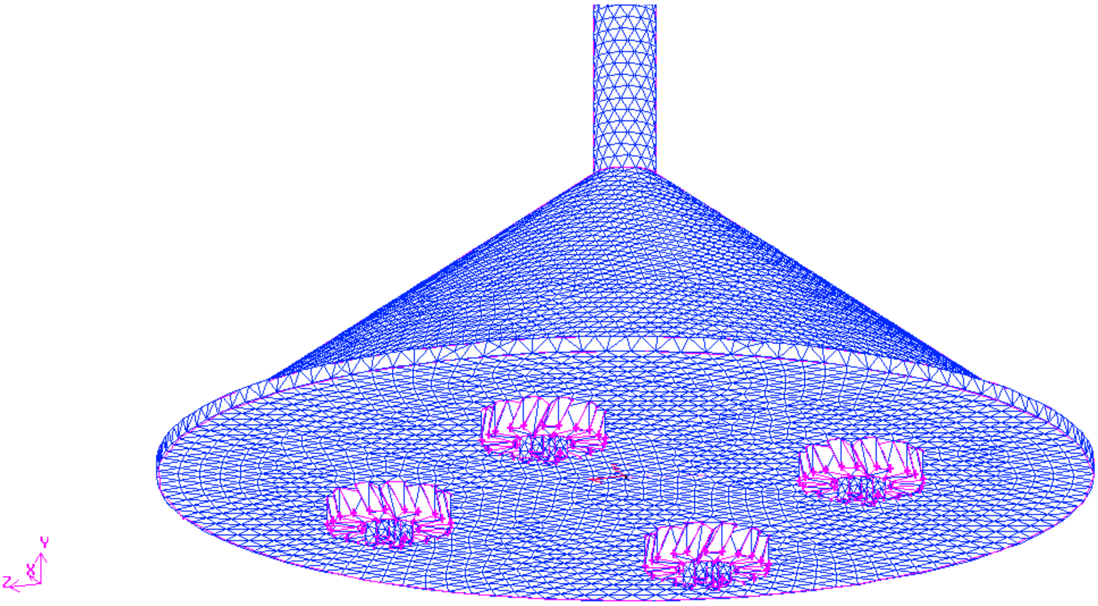


Fig. 5 The domain grid as designed by GAMBIT code

3- Results and Discussion

The heat energy transferred from the flame inside the combustion chamber to circumferential wall which may be built as heat exchanger with another fluid (air or distillated water). This fluid absorbs heat from the wall by convective heat transfer to rotate gas turbine or steam turbine. So, it might be use turbine at chimney depend on the flue gases motion outside the system.

In this paper, three cases of gaseous fuel velocity input depending on the chamber capacity and/or iterate that to capacity of chamber. The cases are 0.05, 0.1, 0.14 m/s of gaseous velocity input through anyone of the four velocity input vents at the base (0.052, 0.105, 0.157kg/s mass flow rate). The central section plane which cut the system into two parts and cut two burners only is taken at this paper. The combustion process is taken for gaseous fuel (methane) density (CH_4 fuel) is 0.6679kg/m^3.

Fig. 6 shows the temperature distribution inside the system. Fig.6A is an indication of heat absorbed or transferred to different trends of parts chose at 0.105kg/s of fuel input flow rate. This shape of temperature range (2200 K to 300 K) which is at ambient temperature of 300 K.

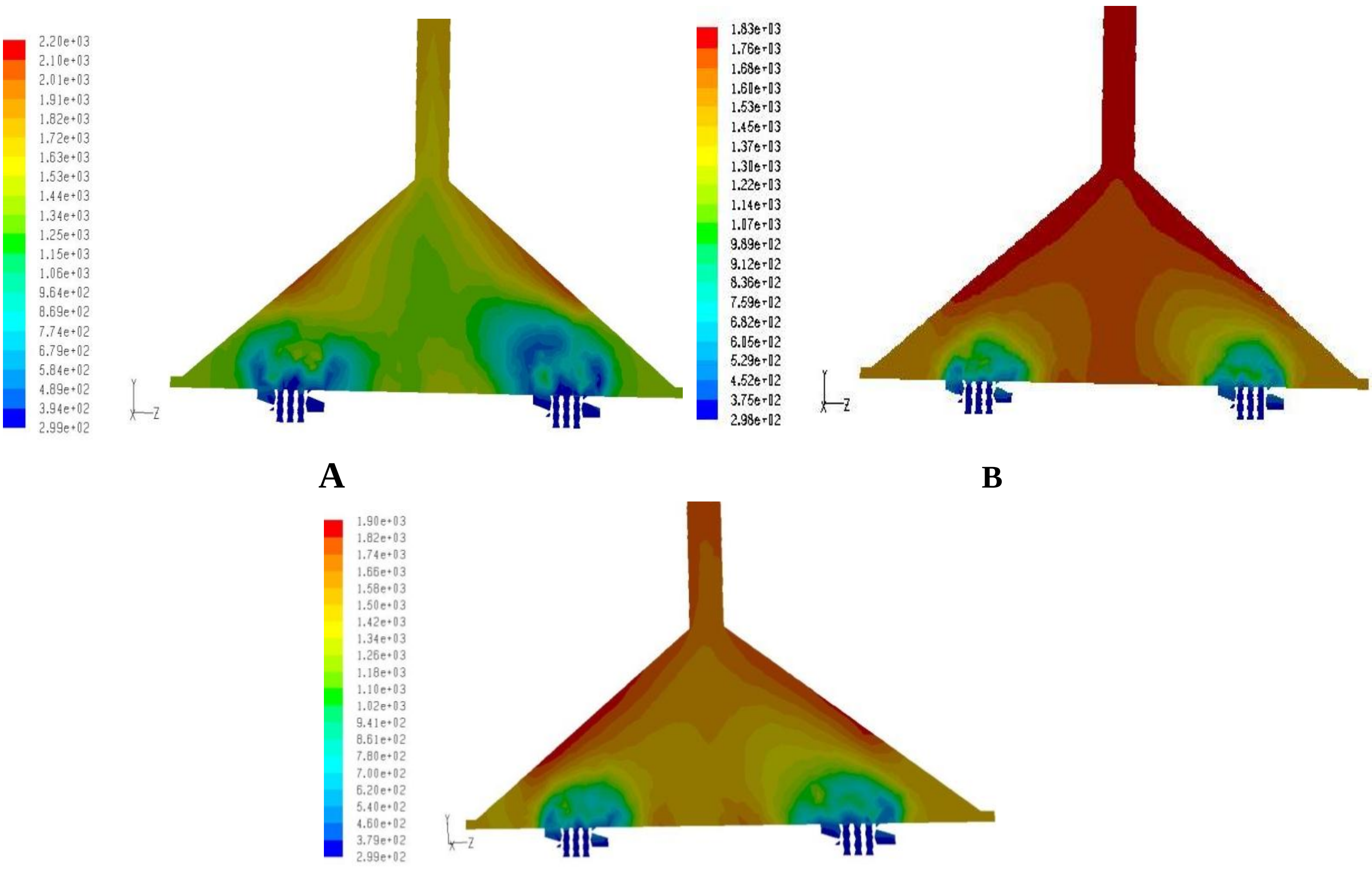


Fig. 6 Static temperature at A (0.105kg/s), B (0.052kg/s) and C (0.157kg/s) of fuel input flow rate

FLUENT Code demonstrates wide ranges of measurements near the effective domain. The dominated temperature of air inside the chimney is 1200K as observed by limited range contour but the maximum temperature value is at the bottom side distance of chimney and inside upper ceiling of the chamber. It is notably high hot place than other system space because the combustion of fuel and air was happen under this place. The air speed increases in the direction of chimney Centre.

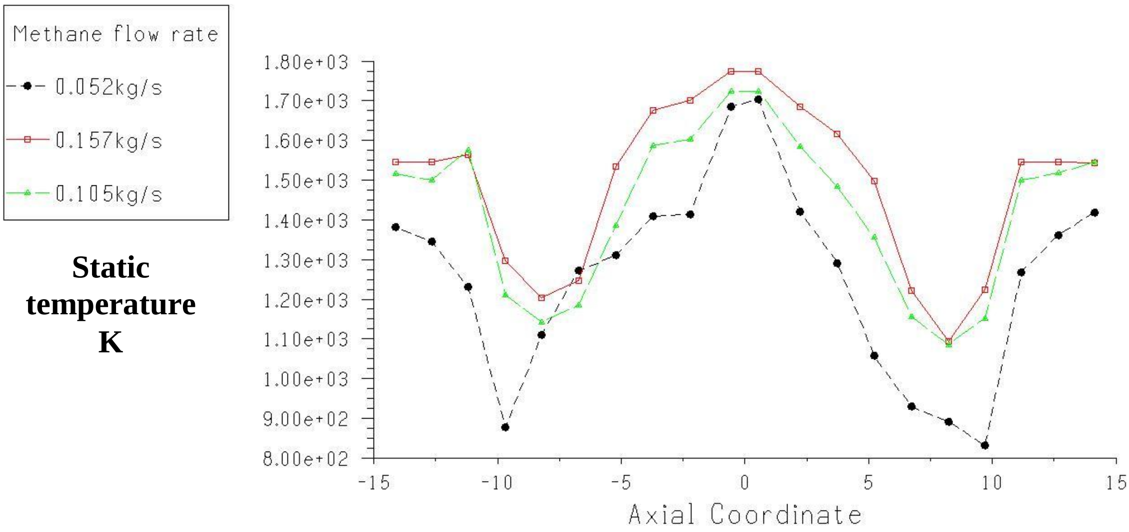
The other shapes of Fig.6B and 6C denote to temperature difference at fuel flow rate of 0.052 and 0.157kg/s respectively. It is normally, there are gradually higher temperature ranges than 0.105kg/s of fuel flow rate. In 0.052kg/s fuel velocity, it is normally lower than 0.2m/s because of lower mass flow rate. But in 0.157kg/s observe lower value too since the combustion process takes place near the chimney base which gone outside the system as shown in fig.6C with yellow colour. This heat forces the velocity magnitude in the direction of chimney Centre as a result to natural convection of air and forced convection of fuel input [10].

Therefore, fig.7 shows the circumferential average of static temperature for three cases of paper study. It is found that the higher value of temperature at the chimney is for 0.157kg/s of fuel as described previously but the lower temperature lies between 0.052kg/s and 0.105kg/s. There is an increasing in the temperature at the left hand side of figure for mass flow rate of fuel 0.052kg/s because of swirling and friction of mixture particles inside the combustion chamber [18].

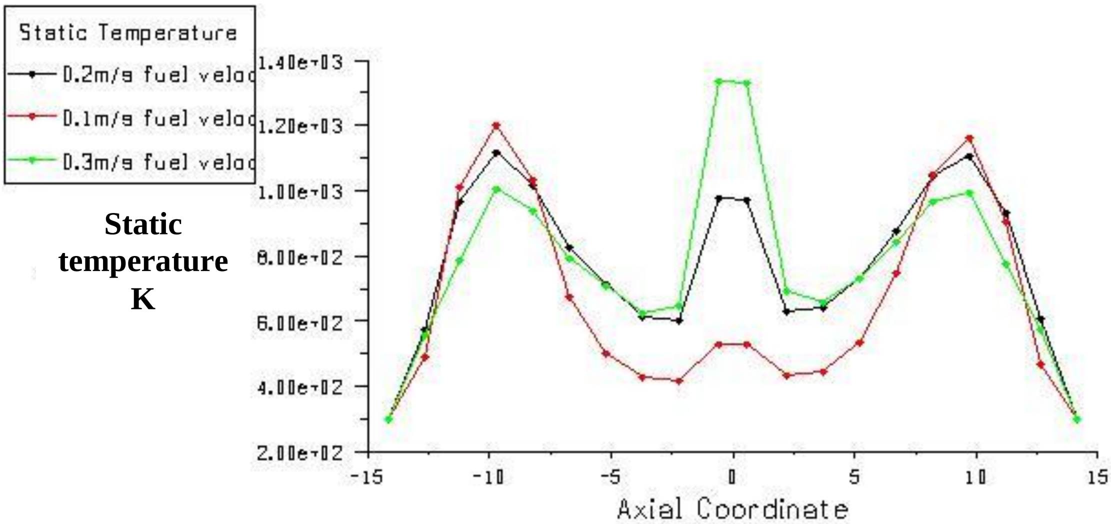
To ensure the validity of this study, the circumferential average of static temperature compared with previous paper [10] in Fig.7-B. The mass flow rates of combusted fuel of this study (0.052, 0.105 and 0.157 kg/s) are similar to that of velocity magnitude (0.1, 0.2 and 0.3m/s) respectively for [10]. The findings of comparison of Fig.7-A with Fig.7-B give that higher temperature at present study (1400-1800)K as a result of new burner design and swirling flow which leads to high turbulent mixing rate for air and fuel particles and high combustion efficiency.

Also, lower temperature is at 10m radially in Fig.7- A because of non-premixed combustion with high mixing rate of burners at this position. The chamber of chimney is closed for the end edge side of base therefore no air input, so, the temperature is high.

The velocity vectors of the system are shown in Fig.8 which indicates that high velocity magnitude at inlet fuel flow rate of 0.105kg/s reaches 5.6m/s at the position of turbine at the lower part of chimney. So, there is a low velocity gradient at the outer end of the base part of system. The velocity notably increases when directed to the chimney Centre due to the heat accumulation increase, narrow area of chimney cover and low pressure gradient. The velocity range increases directly with increasing the heat flux of combustion. These ranges are suitable for using big turbines at lower position of chimney or using multi-stage turbine to have high gain energy.



A



B

Fig.7 Circumferential average of static temperature A:for three present cases and B: for Reference [10]

The circumferential average of velocity magnitude distribution on the system domain with its position in the central section for whole system with axial coordinates is presented by Fig.9A. It is denoted that high velocity values lie at the chimney but low values at the end edges of chamber since the reasons mentioned in this paper before. The upper black curve of Fig. 9A denotes the velocity magnitudes in the axial coordinate calculated as average values of the central section of domain for flow rate of fuel input 0.157kg/s which interpritates high velocity of flue gases of combustion with increase the energy of fuel. It is observed that higher velocity values trend from the outer edge to the central part of domain (chimney) as mentioned before. The validity of these values shown by fig. 9B for Hannun [2] which predict the same trend of curves for different values of power.

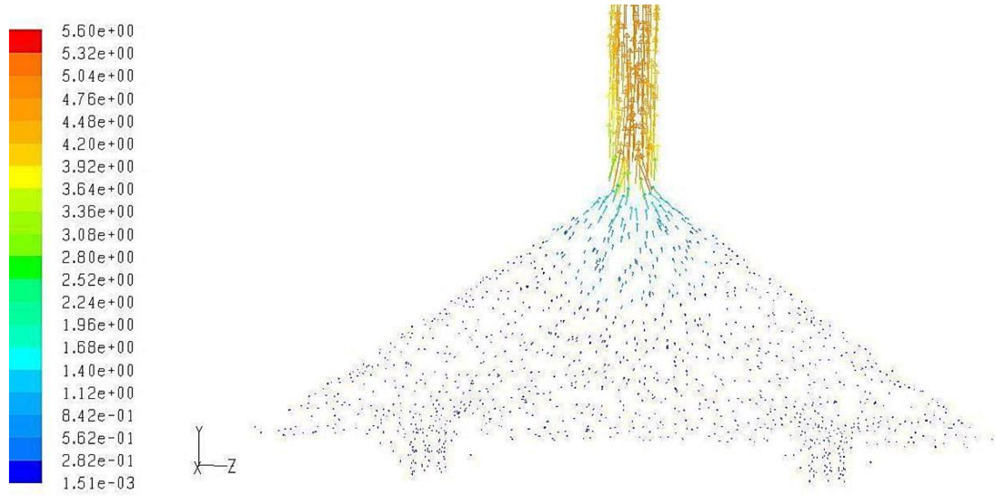
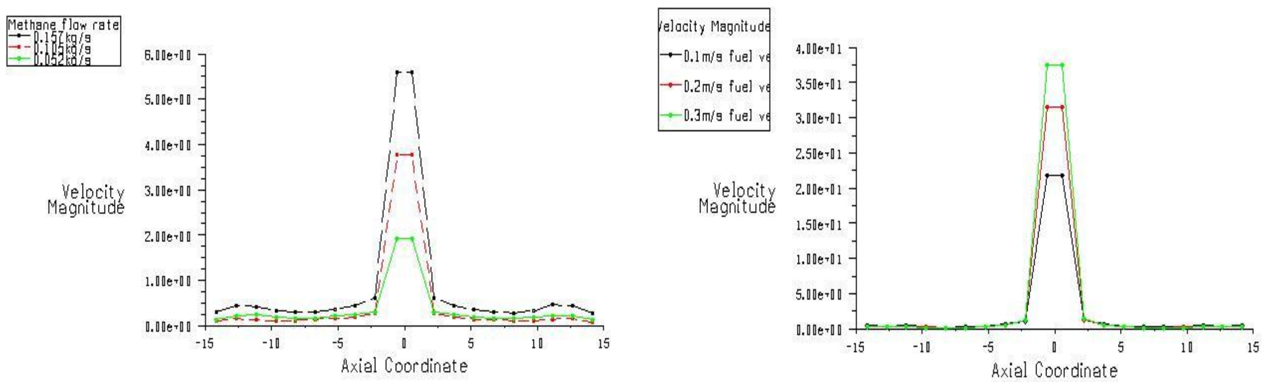


Fig. 8 Velocity vector distribution(m/s) at 0.105kg/s fuel flow rate

So, the validity of this work that the programme code works properly to get logic results. Fig. 10 shows the concentration of species in combustion which is calculated as mass fraction. The first one is the gaseous fuel (methane CH4) which reasonable prediction for incoming fuel from burners to combustion chamber before the combustion process has high mass fraction at this place then circumferentially disappeared after the mixing outside the burner, but the second one for Hannun [10] the fuel concentration gradually disappeared without swirling and mixing process inside the furnace as a result to combustion. The forth is carbon dioxide concentration where it has maximum value at the end of combustion after the reaction complete with the same manner of water particles concentration (Fig. 10). It is vice versa to concentration of oxygen (fifth slip) because it inters the reaction before burning of fuel. The sixth slip is for nitrogen, its concentration is very high in large space of domain except in the combustion space because it is not interring in the combustion process but it has high portion of air constituents.



A **B**

Fig. 9 Circumferential average of velocity magnitude for different velocity input of fuel A for present study, and B for [10]

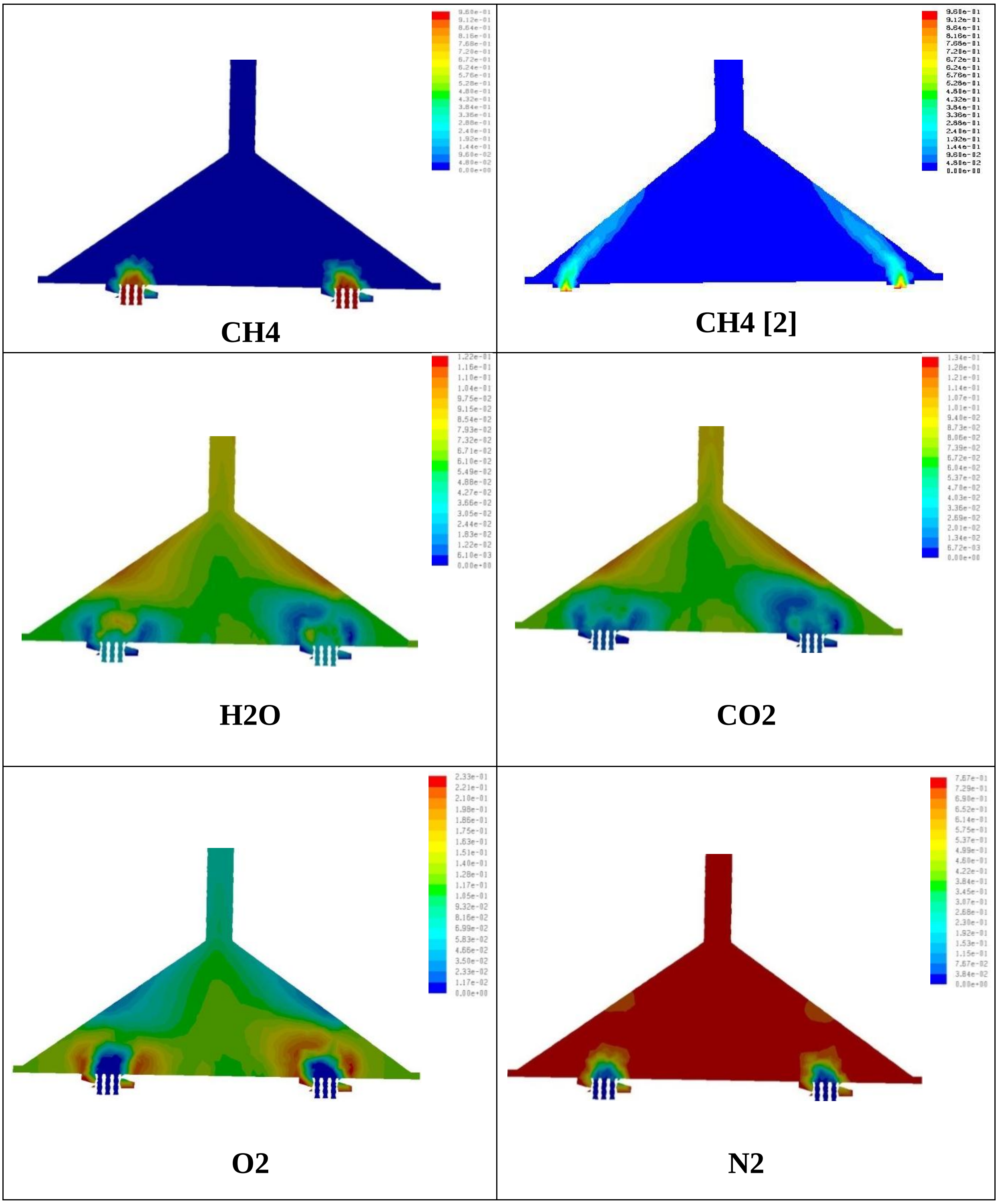


Fig.10 The concentration of species (mass fraction) at 0.105kg/s flow rate of fuel input and [10]

4- Conclusions:

It is noted from the numerical solution and the analysis of chimney tower system for the predicted case study, there are some conclusions presented about the circumferential parameters such as:

1- The present design could be depended to erect in oil stations mentioned in the 1 above or may be arranged to be favorable for anyone.

2- The present design of burners and their situations were enhanced by using swirlers to get complete combustion process with high efficiency.

3- It is reasonable to build a new burner design of chimney tower at the oil spilling units or refinery units to use the compound gases outgoing the petroleum wells.

4- The pressure gradient is approached to atmosphere at the inlet vent of the system but it is increased while reach the top of chimney since high difference in relative pressure due to the heat. Also, the height of chimney which work as vacuum pressure to increase the air velocity.

5- Due to the high velocity recorded at the expansion of chimney, the power turbine is preferred to build in.

References

[1] Hannun R.M.," Modeling of Solar Thermal Power Plant" , M.Sc. thesis, University of Technology, Mechanical Engineering Department, Baghdad, 2005.

[2] Haaf, W., Friedrich, K., Mayr, G., Schlaich, J., "Solar chimneys, part I: principle and construction of the pilot plant in Manzanares", International Journal of Solar Energy 2, 3–20, (1983).

[3] Haaf, W., "Solar chimneys, part II: preliminary test results from the Manzanares pilot plant", International Journal of Solar Energy 2, 141–161, (1984).

[4] Schlaich, J., "The Solar Chimney: Electricity from the Sun", Deutsche Verlags-Anstalt, Stuttgart, (1994).

[5] Sislian J.P., Jiang L.Y. and Cusworth R.A., "Laser Doppler Velocimetry Investigation of the Turbulence Structure of Axisymmetric Diffusion Flames" Progress in Energy and Combustion Science, Vol.14, No.2, PP.99-146, (1988).

[6] Lefebure A.H., "Gas Turbine Combustion", Second Edition, Taylor and Francis Group, UK (London), 1999.

[7] Backström T. and Fluri T., "Maximum fluid power condition in solar chimney power plants –An analytical approach", Solar Energy 80 (2006), pp. 1417-1423.

[8] Pretorius J. P. and Kröger D.G.,"Critical evaluation of solar chimney power plant performance ", Solar Energy 80 (2006), pp. 535 -544.

[9] Ninic N., Nizetic S., "Elementary theory of stationary vortex columns for solar chimney power plants", Science direct, Solar Energy 83 (2009), pp476-476.

[10] Hannun R.M.," Power Generation by Utilizing the Compound Gases with Spilled Oil at Using POWER CHIMNEY Techniques", Journal of Petroleum Research and studies, No.4, 2011, Iraq.

[11] Love N.D., Parthasarathy R.N. and Gollahalli S.R., "Rapid Characterization of Radiation and Pollutant Emissions of Biodiesel and Hydrocarbon Liquid Fuels", ASME, Journal of Energy Resources Technology, (2009).

[12] Azazi F.A., "Aerodynamics and Thermal Prediction of Al-Hartha Power Generation Plant Furnace", Ph.D. Thesis, College of Engineering, Basrah University, Iraq (2001).

[13] Alhabbubi M.M., "Radiative Heat Transfer in Boilers Using the Zonal Method", MSc. Thesis, Mechanical Engineering, Babylon University, (2002).

[14] Sobolev V., Snegirev A., Shinder Y. and Lupulyak S., "Modeling of Turbulent Diffusion Combustion in the Jet Flames of the Rectilinear-Swirl Burners", The 3rdinternational conference "Heat and mass transfer and Hydrodynamics in swirling flows", 21-23 October, (2008), Moscow, Russia.

[15] Hannun R.M., "Three Dimensional Aerodynamic and Temperature Predictions for Nassiriya Power Plant Boiler Furnace", Ph.D. Thesis, College of Engineering, Basrah University, Iraq, 2009.

[16] Hannun R.M., Ugla A.A. and Abid G.A., "Prediction of Power Chimney Parameters Influenced the Operation at Nassiriya City", Thi-Qar University Journal for Engineering Sciences, 2(2), 2011, 84-105.

[17] Tao WQ., "Numerical heat transfer", 2nd ed. Xi'an, China: Xi'an Jiaotong University Press; 2001.

[18] Syred N. and Beer J.M., "Combustion in swirling flows: A review", Combustion and flame, Vol.23, 1974, PP.143-201.

[19] Hannun R.M., Najim S.E., Rishack Q.A., and Syred N., " 3-D. Aerodynamics And Thermal Prediction For Nassiriya Power Plant Furnace By Using Crude Oil Fuel", International Journal of Advanced in Science and Technology, vol.3, No.4, 2011, UK.

NOMENCLATURE

Symbol	Definition
a	Thermal diffusivity (m^2/s).
A_p	Area of the inside faces of combustion chamber (m^2).
g	Gravitational body force (m/s^2)
k	Kinetic energy (m^2/s^2)
L	Combustion chamber canopy height (m).
m_a	Air mass flow rate (kg/s)
M	Molecular weight (kg/kmol)
c_p	Specific heat at constant pressure (kJ/kg. K)
p	The local absolute pressure Pa
R_a	Rayleigh number
T_a	Air temperature (K)
T_f	Fuel temperature (K).
T_w	Wall temperature (K).
u, v	Average velocity at x, y directions respectively (m/s)
W	Weight (kg)
έ	Emissivity factor
ε	Dissipation rate (m^2/s^3)
β	Coefficient of Thermal expansion (1/K)
λ	The heat conduction coefficient (W/m. K)
μ	Dynamic viscosity (kg/m.s)
ν	Kinematic viscosity (m^2/s)
ρ	Density (kg/m^3)