World Academy of Science, Engineering and Technology
International Journal of Mechanical and Mechatronics Engineering
Vol:2, No:11, 2008

Physical Modeling of Oil Well Fire Extinguishing using a Turbojet on a Barge

M. Abbaspour, D. Mansouri, and N. Mansouri

Open Science Index, Mechanical and Mechatronics Engineering Vol:2, No:11, 2008 publications.waset.org/10499.pdf

***Abstract*—**There are reports of gas and oil wells fire due to different accidents. Many different methods are used for fire fighting in gas and oil industry. Traditional fire extinguishing techniques are mostly faced with many problems and are usually time consuming and needs lots of equipments. Besides, they cause damages to facilities, and create health and environmental problems. This article proposes innovative approach in fire extinguishing techniques in oil and gas industry, especially applicable for burning oil wells located offshore. Fire extinguishment employing a turbojet is a novel approach which can help to extinguishment the fire in short period of time. Divergent and convergent turbojets modeled in laboratory scale along with a high pressure flame were used. Different experiments were conducted to determine the relationship between output discharges of trumpet and oil wells. The results were corrected and the relationship between dimensionless parameters of flame and fire extinguishment distances and also the output discharge of turbojet and oil wells in specified distances are demonstrated by specific curves.

***Keywords*—**Burning well, fire extinguishment, gas/oil industry, simulation.

I. INTRODUCTION

THE oil in wells is generally produced and supplied through concentric pipes and flows there through at great pressure together with large quantities of gases. Since this mixture is extremely inflammable, fires sometimes occur and much effort and money has been expended to find ways for extinguishing these fires quickly without causing too great damage to the installation around and above the well [7]. All the known methods for extinguishing fires in oil wells are based on the principle to choke the oil and gas supply through the pipes whereby the fire extinguishes itself. Some methods use detonation of the top of the pipes to carry out this principle while in another method a bore is made at an angle to the wells and mud and liquids are inserted therein so that the ascent of the oil is prevented in the pipes [7].

Fire extinguishing can be achieved by controlling any of the four elements including combusting material, oxygen, flame and chain reactions. Based on this idea four basic fire fighting methods have been developed [9]. Each fire extinguishing procedures may contain one or more of the above methods. Water can be used to cool burning solid materials and foams can be applied to separate the flame from the combusting materials and cooling the flame as well. Dry chemicals can be employed as a means of fire extinguishment through one of the following mechanisms [2], [6]:

1) Interaction with the combusting materials
2) Covering the surface of the combusting element
3) Prevention of the radiation heat transfer

Controlling flame temperature has a very important role in the extinguishing of the fire, since the combustion reaction ($H+O_2 \rightarrow OH+O$) is very sensitive to temperature, i.e., a small decreases in temperature can cause a great changes in the rate of combustion reactions. As a result, two effective ways including decreasing the temperature of the flame by cooling agents and controlling the chain reactions by adding chemical agents can be recommended. Cooling agents can decrease the rate of gas formation to few $gr/m^3.s$, so short after the flame will start to tremble and it will turn off [9].

Changing the percent of air-fuel mixture is another way to cease the fire. Fig. 1 shows that not only by adding excess nitrogen, but also by continuously adding excess air or methane to a combustible mixture, i.e., a 9.5% mixture of methane-air, it can become nonflammable [6].

Traditional methods for fire extinguishment of burning wells were used for many years in various operations but they are not enough safe and efficient. Digging diverting wells and destroying the main well is one of these methods which may encounters the operators on high risk situations and cause adverse effects such as complete destruction of the main well and put the work on unsafe condition. Using a metal case with conducting Ducts is another method which used to extinguishing burning oil wells in Iran. In this method toxic gases and heat radiation endanger the workers during the operation. A metal cabin with a chimney and a few number of nozzles and pipes are used. The cabin should be designed based on the characteristics of the well so the minimum weight of it and the diameter of the cabin chimney should be calculated based on forces applied on the cabin. Dangerous radios from the well decreases when the top cabin is installed. A thermal protective shield or water spraying system may

Manuscript received June 13, 2008.

Majid Abbaspour is with the Department of Mechanical Engineering, Sharif University of Technology, Tehran, Iran (e-mail: m-abbaspour@jamejam.org).

Dariosh Mansouri is with Tarbiat Modaress University, Tehran, Iran (e-mail: mansoury@modares.ac.ir).

Nabiollah Mansouri is with the Science & Research Campus of IA University, Tehran, Iran (Corresponding Author; phone: +9821-912-126-2426; fax: +9821-220-60435; e-mail: nmansourin@gmail.com).

used for the safety of operators against the heat radiation [16].

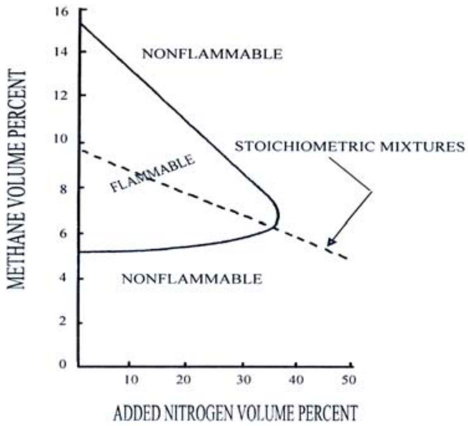

Fig. 1 Flammability range of different nitrogen-air-methane mixtures at temperature of 25°C and pressure equal to 1 Atmosphere

Modern fire extinguishing methods are based on extinguisher powders and using turbojets. In the first way a chamber filled with a fire extinguishing powder is exploded at a certain height above the fire. The powder is distributed over the fire and may extinguish it. In case of offshore operations, the chamber usually is carried out by a route connecting to masts of two barges. A remote control system can be used to explode the chamber [16]. In another technique firefighters attack flames with 3,000-pound extinguishers that spray dry powder (Purple K) at a rate of 200 pounds a second. Then, using steady streams of water in conjunction with the dry chemical extinguishers, they put out the flames. If oil has pooled on the ground, firefighters may spray it with foam that breaks the oil down at the molecular level. Once the fire is out, firefighters spray the surrounding area with water, carefully avoiding the still-flowing oil geyser [8].

Fig. 2 A typical turbojet for land based activities

Using turbojets to control the oil well fire is one of the most modern fire extinguishing methods which was applied successfully by an American Company to extinguish offshore oil wells in Kuwait (Fig. 2). In this method a truck is used to approach a turbojet towards the flame. The turbojet strength should be design according to the flame characteristics, so that it can skew the flame toward opposite side and allow operators to extinguish the fire more efficiently [1]. This method has not been applied anywhere onshore.

II. Material and Methods

This work was conducted to determine the main characteristics of the turbojet and extinguishing tools need to stop the fire in a burning oil well via physical modeling of the system. For this purpose two set of equipments were needed to build up the test set up (Fig. 3) as follow:

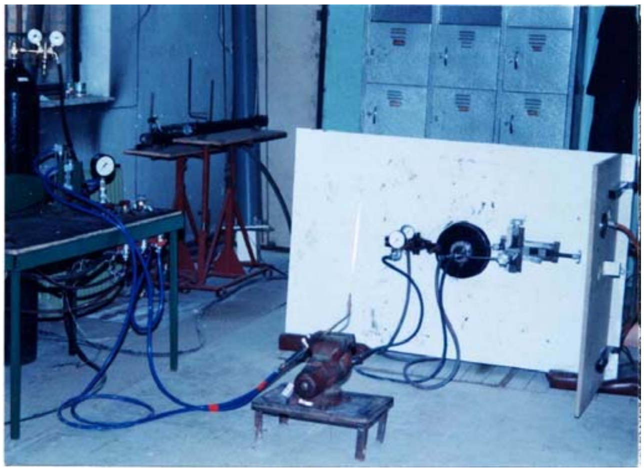

Fig. 3 The test setup

A. Jet Flow Equipments

The following equipments were used to build up the testing jet flow set:

Screw type air compressor, type 250, manufactured by Atlas Copco Company with a pressure of 80 psi and a flow rate of 0.025 m^3/s. The produced compressed air was unified by a unifying tank; meanwhile the input pressure and temperature of nozzle were measured [12]. The more the flow rate of the compressor, the better results will achieve. In addition, higher speed and a larger cross section of jet flow can be achieved.

Divergent and convergent nozzles were flanged to the tank. Flange system allowed examining different nozzles with different profile. Used conical nozzles were made of stainless steel.

A testing table was used to install the tank and nozzle. This table was designed to have minimum possible vibration. Other testing equipment such as *a pressure gauge, a pitot velocity meter*, and *a thermometer* were also installed on the table.

B. Flame Requirements

To simulate the burning oil well, a laboratory scale flame was examined (Fig. 4). Apparatus to produce such a flame were as follow:

1. Liquid Gas Cylinder: A typical household liquid gas cylinder.
2. Fuel Regulator: To adjust the pressure (O.133 bar)
3. Rotameter: To measure the fuel flow rate.

Open Science Index, Mechanical and Mechatronics Engineering Vol:2, No:11, 2008 publications.waset.org/10499.pdf

4. Gas Rubber hose: 8 meters long.
5. Couplings: To fix inputs and outputs of the hoses to the fuel tank, rotameter and to the pack.
6. Oxygen Tank: High pressure industrial type.
7. Regulator for oxygen: To adjust the oxygen output pressure to 2 bars.
8. Rotameter for Oxygen: An air rotameter which calibrated with oxygen was used.
9. Oxygen Rubber hose: 8 meters long
10. Pack: To turn on the fire (2 mm output diameter)
11. Thermocouple: To measure the temperature of the flame
12. Holders: To fix the pack on the table.

Fig. 4 A view of the flame in the test

C. Test Description

The test was designed in five separate experiments. In the first one, fifteen flames were made by means of the pack. The different flame lengths have been produced and tested. The ratio of fuel to oxygen flow was constant for each of five-flame group, so there were three groups include: reach fuel, poor fuel and almost a stokiometeric condition ($\phi = 1$). In fact, the output of the fuel and the oxygen were adjusted in the pack for a desired ratio of fuel /oxygen flow and then the flame length was measured.

In second experiment, fifteen flames were also used as the above mentioned experiment. Then, the necessary flow rate of the air from the nozzle to extinguishing the flame was measured at a constant distance. In third experiment, the flow rate of the nozzle was kept constant and the extinguishing distance, the distance between the nozzle and the flame, was measured for each of the flames.

Forth experiment was performed by three lengths of flames. Each one at three measured constant distances was turned off at different flow rate of extinguishing nozzle which recorded under each condition separately.

At the fifth experiment, three different constant flow rates of nozzle were considered for extinguishing the fifteen different lengths of flames by changing the ratio of fuel/oxygen flow at each distance.

To facilitate the experiments, the following substitutions were made.

1. Instead of crude oil, methane was used as fuel.
2. Instead of air, oxygen was used for flames
3. Oxygen and the fuel were premixed in the pack; however it is better to use two concentric pipes.
4. The hot air exited from the nozzle was taken as the hot air exiting from a turbojet.

To determine the important parameters which use in modeling, the dimensionless characteristics of the axial coordinates, the main parameters should be identified firstly and then the dimensionless numbers could be known using Buckingham theorem finally. The most significant dimensionless numbers in fire extinguishments can be introduced [10], [14].

D. Effective Parameters in the Test

Effective Parameters on the Nozzle Output:

Density (ρ), Velocity (V), Pressure (P), Dynamic viscosity (μ), Speed of sound (C), Thrust (F), Time (t), Flow rate of the nozzle (Q)

$$f\ (\rho, V, P, D, \mu, C, F, t, Q) = 0$$

Using Buckingham theorem and considering parameters P, V, and D for dimensionless procedure, the important dimensionless standard numbers and the ratios of the above function are as follow:

- Mach number
- Reynolds number
- Euler number
- Velocity ratio
- Time ratio
- Flow rate ratio
- Force ratio

Effective Parameters on the Flame:

Temperature difference between the flame and the surroundings (θ)

Heat transfer coefficient (h)

Thermal conductivity coefficient (k)

Specific heat capacity (C)

Thermal expansion coefficient (β)

Density of the fuel mixture ρ

Air density (ρ_a)

Open Science Index, Mechanical and Mechatronics Engineering Vol:2, No:11, 2008 publications.waset.org/10499.pdf

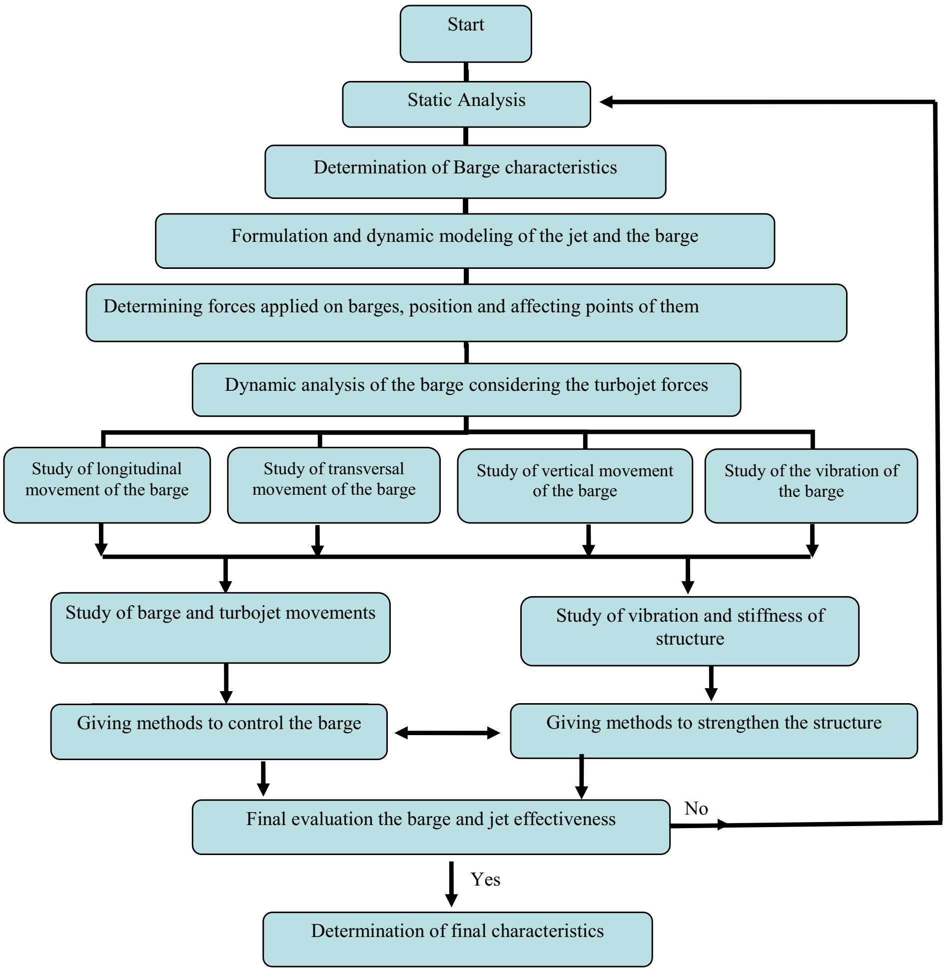

Fig. 5 Plan diagram of activities for controlling the fire in a burning oil well in offshore using a turbojet in a barge.

Flow rate of the fuel mixture (Q)
Velocity of the fuel mixture (V)
Diameter of the valve (D)
Output pressure (P)
Gravitational acceleration (g)
Speed of the sound for the fuel mixture (C_s)
Surface tension (σ)
Flame length (*l*)
Flame velocity (V_f)
Dynamic viscosity factor of the fuel mixture μ

$$R(\theta, h, k, c, \beta, \rho, \mu, V, D, P, g, C_s, \sigma, l, V_f, Q, \rho_a) = 0$$

Using Buckingham theorem and considering parameters ρ, V, D and θ for dimensionless procedure, the following dimensionless groups can be defined [15]:

- Reynolds number
- Euler number
- Frude number
- Mach number
- Weber number
- Krashov number
- Nusselt number
- Peclet number

Among the above mentioned dimensionless numbers, the most important ones were selected as the characteristics of the coordinate axis of the extinguishment index [15].

III. Results and Discussion

In order to study oil well fire extinguishing process on sea, several issues should be studied. Selection of a suitable barge for carrying the turbojet from the static's, dynamics and the structural behavior view points, is very important (Fig. 3). Regarding to the oil well, the following parameters should be studied:

I) oil well flow rate could be estimated regarding the following means and characteristics:

a) Sonar systems
b) The flame height

Open Science Index, Mechanical and Mechatronics Engineering Vol:2, No:11, 2008 publications.waset.org/10499.pdf

c) Radiation from the well
d) Computer software

II) Heat production form burning well.

III) Flow rate of the gases produced in combustion process.

IV) Ideal flame temperature, considering excess air and relative humidity moisture.

V) Safety distance from the well

VI) Process of cooling the flame by water

All calculations for selection of the barge [11], [3] and turbojet [4] for appropriate well have been done, and their contributions to fire extinguishing process were calculated [5]. Fig. 5 shows the plan diagram to define and finalize the important characteristics of all elements in extinguishing activity for controlling the fire in a burning well in offshore using a turbojet in a barge.

Fig. 6 shows the variation of dimensionless flame height as a function of dimensionless fuel/oxygen mixture. This diagram was strongly correlated with the diagrams presented by other researchers such as those at 9th International Symposium on Combustion [13].

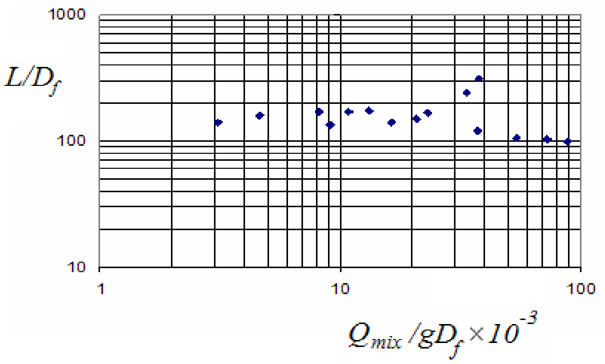

Fig. 6 Dimensionless flame height for different fuel/oxygen mixture

Fig. 7 shows the dimensionless flame height at three different ratios of fuel/oxygen mixture. According to this diagram, an increase in flow rate of the fuel from oil well, signifying more fuel rather than oxygen content, resulting in less nozzle air flow rate needed for extinguishment. The reason is that by increasing the flow rate of the oil or gas from the well, the area of the flame will increase and the contact between the flame and the well will reduce, therefore the flame can be easily separated from the well.

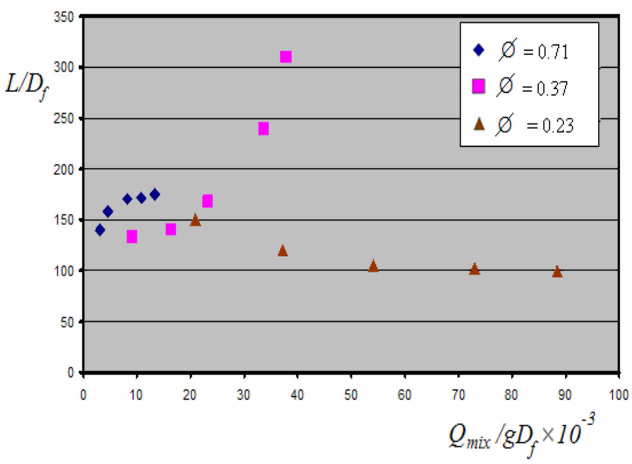

Fig. 7 Dimensionless flame height at three different rations of fuel/oxygen

Fig. 8 shows the fluctuations of oil or gas flow rate from the well on the needed flow rate of turbojet for extinguishing. It clearly shows that by decreasing the ϕ (Q_{Fuel}/Q_{Ox}), the flame intensity will increase and the extinguishable area will decrease resulting in high heat radiation and subsequently difficulty in turning off the fire due to longer extinguishing distance. Dimensionless flame heights based on extinguishment distance are shown in fig. 9 which can be used for determining the extinguishment distance of a burning oil well. Knowing the ratio of *l/D* (flame length/ well diameter) and the Q (flow rate of the oil well), ϕ of the burning oil well can be calculated. After obtaining the amount of Q and ϕ (from Fig. 8) flow rate of the oil well output can be calculated using the results of the second experiment (Fig. 8). Knowing the ratio of *l*/D and ϕ, the results of the third experiment (Fig. 9) can be used to determine extinguishment distance.

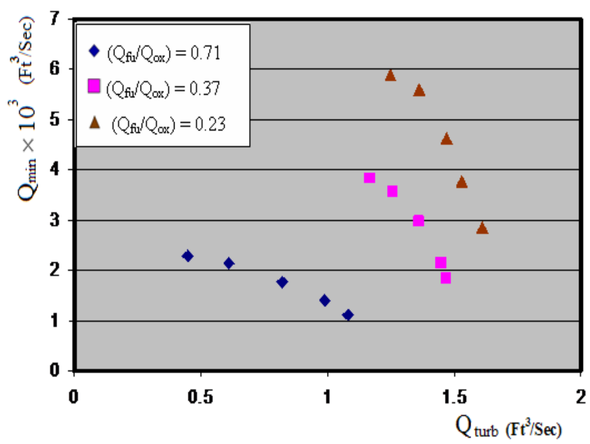

Fig. 8 Flow rate of the turbojet to the flow rate of the oil well

Open Science Index, Mechanical and Mechatronics Engineering Vol:2, No:11, 2008 publications.waset.org/10499.pdf

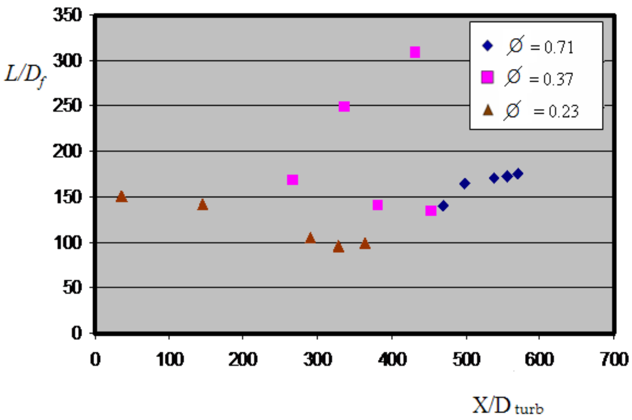

Fig. 9 Dimensionless flame height to extinguishment distance

By the results obtained from three groups of experiments are shown in Fig. 6-9 three curves were drawn for three different ϕ; so that for each flame with a constant ϕ, the extinguishable area and the non-extinguishable area can be determined. These help fire extinguishers to select appropriate condition to achieve better extinguishing results, saving time and reduce extinguishing cost.

IV. Conclusion

Based on the overall results from the simulated experiments, it can be concluded that since the heat intensity around a burning oil well is considerable high, so that approaching the burning well is always a matter of concern and is the most problem in extinguishing process, a turbojet system can be used for deviating the flame; and then the fire could be extinguished by cooling the environment by means of water or foam spraying on the well from shorter distance.

References

[1] Anderson, J., John D., “Fundamentals of Aerodynamics”, McGraw-Hill Companies, 1991.
[2] Arthur E. Cote, Peterson, M. E. “Fire Protection Handbook” National Fire Protection Association, 2003.
[3] Bryan B., Derrett D. R., Capt, “Ship Stability for Masters and Mates”, Butterworth-Heinemann, 2006.
[4] Charles, E., Otis, “Aircraft gas turbine power plants”, Aviation Maintenance Pub, 1997.
[5] Evans, Frank L. “Equipment design handbook for Refineries and Chemical Plants”, Gulf Publication Co., 1979.
[6] Friedman, R., “Theory of Fire Extinguishment, Fire Protection Handbook”, 17th Edition, ed A.E. Cote (NFPA), 1991.
[7] Hefetz, Uriel, "Method and device for extinguishing fires in oil wells", (Patent), U. S. Patent number 3973631, 1976, Available at: http://www.freepatentsonline.com/3973631.html.
[8] Julia Turner, “How do you extinguish a oil-well fire?” 2003, Available at: http://www.slate.com/?id=2080469
[9] Kenneth Kuan-yun K., “Principles of combustion”, Weily-Interscience, 2005.
[10] Langhaar H. I., “Dimensionless analysis and theory of models”, John Wiley & Sons, 1971.
[11] Lewis, E.V. “Principles of Naval Architecture; Society of Naval Architects, 1990.
[12] Mazaheri, K., Shahidinegad, “Study on the behavior of supersonic jet” (in Persian), Third Annul Conference of Mechanical Eng., The Society of Mechanical Eng., Amir Kabir University, March, 1995, Tehran, Iran.
[13] Ninth International Symposium on Combustion, Cornell University, Ithaca, New York, August 27 to September1, Combustion Institute, 1962.
[14] Raghunath, H.M. “Dimensional Analysis and Hydraulic Model Testing”, Asia Publishing House, 1967.
[15] Sedov L. I., ‘Similarity and dimensional methods in mechanics”, Tenth Edition, CRC, 1993.
[16] SUT, Mechanical Eng. Dept., “Traditional Control of Oil well Fire”, (in Persian) Sharif University of Technology, 1987.

Open Science Index, Mechanical and Mechatronics Engineering Vol:2, No:11, 2008 publications.waset.org/10499.pdf