Optimally Economic Design of Flare Systems

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Abstract— **Flares are one of the important parts of oil and gas refineries that burn and safely dispose purge gas. The necessity of energy economy and preventing losses is an important issue in study of flares. Nowadays scientists and engineers work on zeroflareing which has leaded in various physical, chemical and even biological methods of waste management. In this paper having concentrated on cost factors of flares such as height, diameter, horizontal distance to nearest tower, wind velocity, gas temperature, civil and erection costs, the optimum point of flare designing is obtained through using genetic algorithm toolbox. Intermediate crossover function was used while applying GA. Optimization was repeated 50 times by different initial conditions and the average of output data is presented as ultimate one. The effect of wind velocity, Gas temperature, flare height, Gas Mach number, temperature and height of the region in which flare is installed are shown with curves and graphs for several Iranian towns and three different gas temperatures. The obtained results show that the cost of flare will reduce approximately 26%. Parameters such as total gas flow rate, specific heat ratio and pressure of purge gas and its heating value are as per Iranian natural gas typical specifications.**

Index Terms— **Flares, Genetic Algorithm, Optimization.**

I. NOMENCLATURE

D	Inner diameter of the flare	m
T	Temperature of the flare gas	K
H	Height of the flare	m
R	Horizontal distance from reference point	m
Q	Gas flow rate	kg/s
P	Pressure of gas inside the flare	kpa
M	Molecular weight	kg/mole
Hv	Heating value	kJ/kg
L_f	Flame length	m
ΔX	Horizontal distance between flame tip and flare tip	m
ΔY	Vertical distance between Flame tip and flare tip	m
U	Velocity	m/s
S	Minimum allowed distance between center of flare to nearest object	m
Greek Symbols		
ψ	Maximum allowed irradiation	watt/m^2
φ	Released heat by combustion at top of flare	Kw
Non-dimensional Numbers		
Mach	Mach number [U/a]	
K	Specific heat ratio	

II. INTRODUCTION

Since 100 years ago flares have been widely used in upstream rigs, petrochemical plants and any other facilities that need purging gas in Iran. Although scientists and engineers have presented different designing methods for conventional flares, not enough attention has been paid to financially optimizing these structures. According to the authors study there has not been an attempt on financially optimizing flares using GA. Authors consider this field of study a wish.

III. CONTENTS

The scope of this paper is to design and optimize a flare which will be constructed in a refinery plant knowing the gas flow rate, temperature and pressure of gas inside the flare. The revolutionary method of Genetic Algorithm (GA) is used to financially optimize the parameters of design. For this reason the GA toolbox of the Matlab software has been used. Some parameters are assumed at typical amounts such as: ψ, Q, M, K, HV but the problem can be easily solved by changing the amounts of these parameters in the beginning of solution. It has been assumed 32 km/hr for the wind velocity (U_∞). At the end a comparison would be made between the cost of optimized flare and an ordinarily designed flare. To optimize the flare we need a cost function which is the objective function in GA. Cost function was assumed as the accumulation of several cost terms. Cost terms are obtained from foundation, horizontal and vertical piping from a reference point, igniters, windshield, steel structure, power facilities, wiring and designing. The objective function F is as follows:

F= foundation + piping + igniters + windshield + steel structure + power facilities + designing (1)

The cost of designing is assumed as 5% of the total cost. Following, the method of evaluating the cost of each term is described individually.

A. Flare Cost

1) Foundation

The cost of foundation=a1*V (2)

Here a_1 is the cost of one cubic meters of foundation and V is the total volume of it.

2) Piping

The cost of piping =a2*{R+H) (3)

Here a_2 is the cost of one meter of pipe with the diameter of D.

3) Igniters

The cost of igniters =a3*N (4)

Here a_3 is the cost of one igniter and N is the number of igniters

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which is a function of D.

4) *Windshield*

The cost of windshield is assumed to be 20000 $.

5) *Steel structure*

The cost of steel structure = $a4*W$ (5)

Here a_4 is the cost of one kilogram of steel structure including all of its cost such as designing, material, welding, etc. and W is the weight of steel structure.

6) *Power facilities*

The cost of power facilities is assumed to be 10000 $. In order to compare the cost difference between an optimized flare with the use of GA and an ordinarily designed one, in the following lines a flare will be designed through these two methods and ultimately a comparison will be made between them.

B. Flare design

According to the standard of EP-R_460 flare is designed as follows, using Fig. 1 [1].

Assumptions:

$Q=12.6$ kg/s, $M=46.1$ kg/kmol, $T=422$ K, $HV=50000$ kj/kg
$K=1.1$, $P=101.3$ kpa (absolute), $U_\infty=8.9$ m/s.

The flare is assumed to be built 45.7 meters far from reference point ($R=45.7$).

1) *Calculation of Flare diameter*

For Mach=0.2, the flare diameter is calculated as follows:

$$Mach=(11.6)(10-2)(Q/PD2)\sqrt{T/KM} \quad (6)$$

Then; $D=0.46$ m.

2) *Calculation of Flare length*

The heat released in kilowatts is:

$$\varphi=(HV)Q=6.3*10e5 \text{ kw} \quad (7)$$

From Fig. 2 the flame length (L_f) will be read 52 meters.

3) *Flame distortion by wind velocity*

The vapor flow rate is determined as follows:

$$Flow = Q*(\text{Volume of 1 mole})/M * T/273$$

$$Flow = (12.6)(22.4/46.1)(422/273)=9.46 m^3/s \quad (8)$$

The flame distortion caused by wind velocity is calculated as follows:

U_∞/U_j=Wind velocity/Flare tip velocity

U_j is determined as follows:

$$Uj=Flow/(\Pi D2/4) \quad (9)$$

$U_j =56.9$ m/s

$U_\infty/U_j =8.9/56.9 = 0.156$

From Fig. 3:

$\Delta Y/L_f = 0.35$

$\Delta X/L_f = 0.85$

$\Delta Y = (0.35)(52) = 18.2$ m

$\Delta X = (0.85)(52) = 44.2$ m

4) *Flare stack height*

Having taken into consideration the humidity, Fraction of heat radiated F, is assumed to be 0.3. Maximum allowable radiation, ψ, from the flare stack is 6.3 kw/m^2 from table 1.

$$S=\sqrt{(F\Phi)/(4\Pi\psi)} \quad (10)$$

$S=48.9$ m

$$H'=H+1/2\Delta Y \quad (11)$$

$R' = R-1/2\,\Delta X$

$R' = 23.7$ m

$$S^2=R'^2+H'^2 \quad (12)$$

$H' = 42.8$ m

$H =42.8-1/2(18.2)$

$H=33.7$ m

C. Optimization of Flare using Genetic Algorithms (GA)

It is needed to define an objective function in order to use GA for optimizing flare cost. This function is the total cost of designing and construction of a flare system. For this case, the following function is introduced as objective function regarding equation (1). Assuming: $a_1=2$, $a_2=6$, $a_3=400$, $a_4=20$, $F=[2V+6(R+H)+400(N)+20000+20W+10000]*1.5$.

The coefficient 1.5 is because of design factor. Using the GA toolbox of MATLAB and converting the above function into a two-variable function of R and Mach and taking into consideration the effect of constrains on objective function as penalty, the following M-file was written. To convert the objective function introduced before into a two-variable function, the following assumptions have been made. $V=a5*(W+$ the weight of pipe), W=steel structure weight, the weight of tube$=\Pi DtH*7800$, t=the thickness of tube. The coefficient 7800 is the density of steel. Other assumptions can be seen in the M-file. The constrains which have been considered are as follows: $0<R<200$, Because of limitation of space allocated, $0.1<Mach<0.5$, Required for normal function of Bluff body which is an internal part of flare tip [2]. $10<H<100$, for safety and difficulties of construction and wind [3], [4]. $H/D>K$, Because of construction problems [4]. Now we study the effect of few parameters on flare cost. In following interpretations whenever not mentioned, R=50 m and Mach=0.2 and other parameters are fixed Like the beginning of paper.

D. Wind velocity

In Fig. 1 it can obviously be seen that the more the amount of wind velocity, the more the cost of flare would be. Simply, wind tilts the flame, affects the radiation distance and forces the designer to design a higher flare or increase the Piping length.

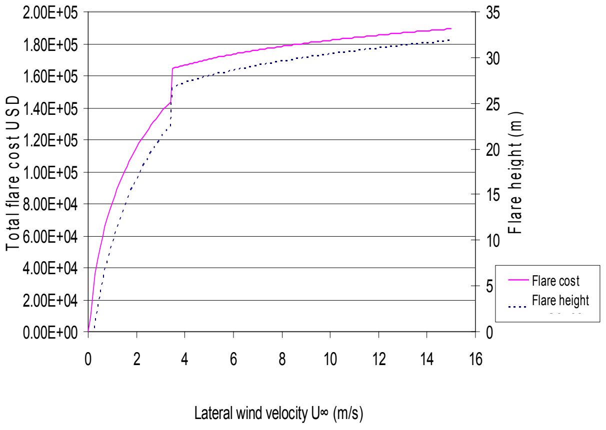

Fig. 1: cost versus wind velocity U∞

There is a jump in the curve. For normal velocities it is usually needed to install 2 or 3 igniters. A company standard offers the number of igniters as a function of diameter D [5]. The jump is because of the third igniter & its costs which are added when the wind speed exceeds almost 4 m/s. According to statistics of wind speed for Iranian towns, an estimated cost of 160 to 250 thousand USD is expected [6]. In Fig. 2 it can be seen that a more piping length results in a cheaper flare cost. The only extremum in the curves is because when we choose R=0 the wind speed transfers the flame further and the outcome is desired but when the R is almost 20 meters the wind brings flame closer to the objects around which worsens the situation and forces the designer to build a higher flare. The extremum point depends on other gas parameters. In Fig. 3 the curves show that it is better to design a flare according to the average wind speed of seasons, since there is almost 30 Thousand USD difference in cost and the designer doesn't have to design for the worst situation.

E. Gas temperature T

The effect of purge gas temperature on cost can be seen in Fig. 4. It shows that a high temperature well or petrochemical plant is followed with more expensive flares and the relation is linear.

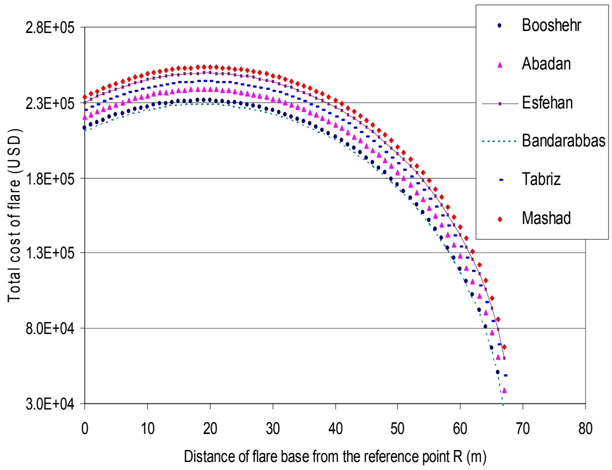

Fig. 2: Cost versus R for several Iranian Towns

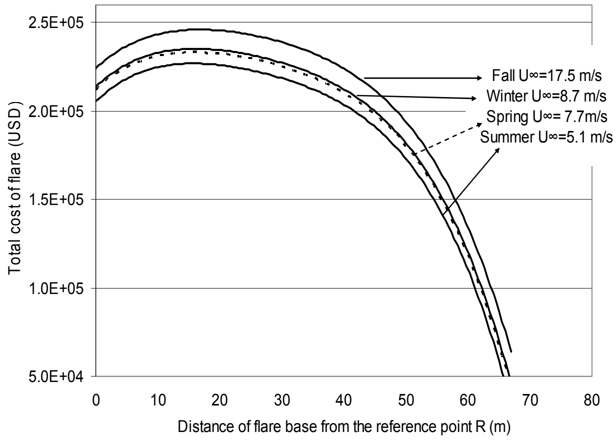

Fig. 3: Cost versus R for different seasons in Abadan

F. The effect of the region height from sea level

Height of the region has an indirect influence on the cost. Height causes difference in air pressure & air pressure causes change in D and so on according to relation (1). Correlation between height from the sea and air pressure is obtained from the standard atmosphere table [7]. The linear relation shown in Fig. 5 can be interpreted in the following way. The air pressure changes, affecting the Mach number at flare tip while the gas is discharged to atmosphere. As it was shown in the beginning, Mach number is a basic parameter for designing that affects D. For example a flare which is installed in a region with 1500 m above sea level is 18 thousand USD more expensive then the one close to the sea.

G. Flare height

Fig. 6 shows that there is a linear relation between flare height and cost. For example a 10 m increase in flare height causes 40 thousand USD more cost. Therefore a lower flare with bigger R is preferable. There is a constraint in lower limit of flare height. In order to diffuse the pollution the flare needs to be risen up to a height so that the wind speed is enough to diffuse the pollution.

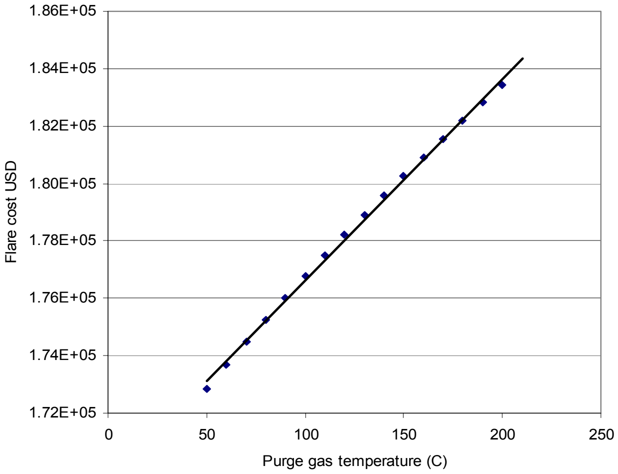

Fig. 4: The effect of gas temperature T

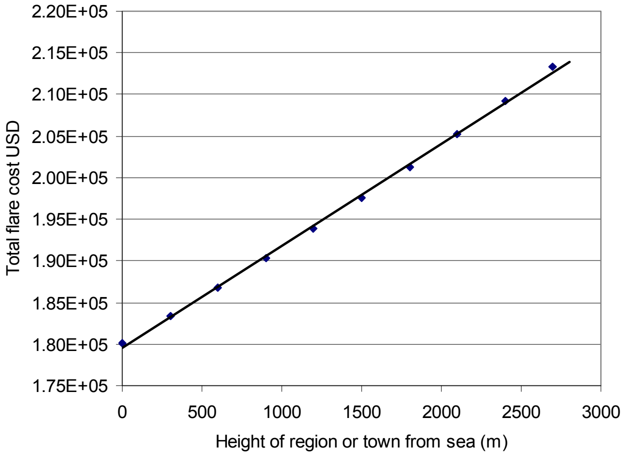

Fig. 5: The effect of Height of region from sea

H. Gas Mach number

In Fig. 7 the correlation between gas Mach number at flare tip & cost of flare is shown. It is interpreted that Mach number highly influences the cost because higher gas speed needs lower diameter piping. As it can be seen in Fig. 7, there is 125 thousand USD difference between a flare which works at Mach=0.1 and a flare which works at Mach=0.4. But there is a technical problem that limits the Mach number to 0.5. There is a part in conventional flare tips called bluff body [2]. The bluff body mixes air & gas at flare tip & produces the jet to be ignited by igniters and makes the flame. The structure of bluff body is such that it can not work with Mach numbers more that 0.5.

I. Ambient Temperature

It has an indirect effect on flare design & total flare cost. As it can be seen in equations (1) to (9), this parameter doesn't appear in the calculations but when the purge gas comes out of well or chemical units, there is a heat transfer along the piping to the flare between gas & surrounding air. The ambient temperature is an important parameter in the process of heat transfer. Finally when gas reaches the flare tip, it has the temperature of T. the effect of T on flare cost has been shown in Fig. 4.

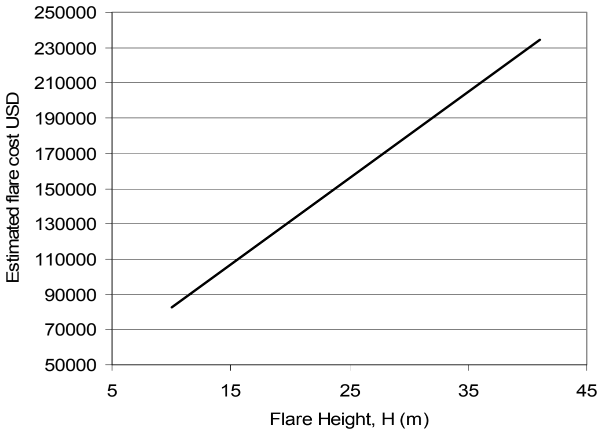

Fig. 6: cost versus Flare height

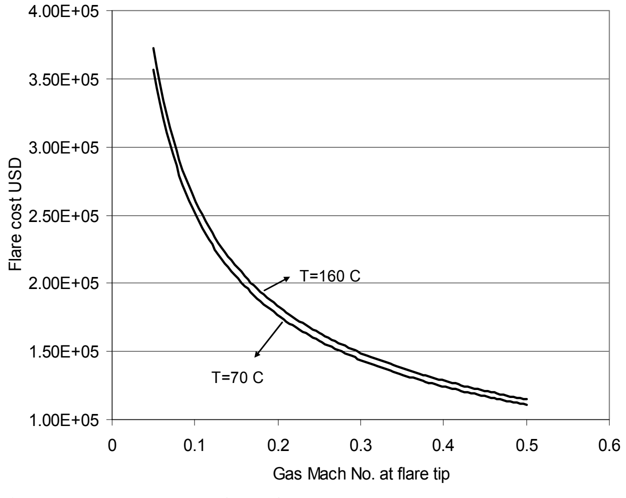

Fig. 7: cost versus gas Mach number

IV. COMPARISON

During the ordinary design which was seen before, the amounts of R and Mach were selected 45.7 and 0.2 respectively. With these amounts, the cost of a flare will be: 195870 $. GA was repeated fifty times with the following circumstances: As it can be seen, the cost of a flare will be 143923 $ therefore the cost reduction is 26% which equals to 51947 $.

V. CONCLUSION

These pages were prepared to show how the cost of construction of a flare system can be reduced for a plant through using the tool of GA. As it can be seen, using an optimization method especially GA can reduce total cost of construction of a flare system in a large amount. The cost of construction of a flare system is very high. Here it can be seen that using GA can reduce this cost up to 40% and the saving is very noticeable.

APPENDIX

TABLE 1: PERMISSIBLE DESIGN LEVEL OF RADIATION [1].

PERMISSIBLE DESIGN LEVEL KILOWATTS PER SQUARE METER	CONDITIONS
15.77	HEAT INTENSITY ON STRUCTURES AND IN AREAS WHERE OPERATORS ARE NOT LIKELY TO BE PERFORMING DUTIES AND WHERE SHELTER FROM RADIANT HEAT IS AVAILABLE, FOR EXAMPLE, BEHIND EQUIPMENT
9.46	VALUE OF AT DESIGN FLARE RELEASE AT ANY LOCATION TO WHICH PEOPLE HAVE ACCESS, FOR EXAMPLE, AT GRADE BELOW THE FLARE OR ON A SERVICE PLATFORM OF NEARBY TOWER. EXPOSURE MUST BE LIMITED TO A FEW SECONDS, SUFFICIENT FOR ESCAPE ONLY.
6.31	HEAT INTENSITY IN AREAS WHERE EMERGENCY ACTIONS LASTING UP TO 1 MINUTE MAY BE REQUIRED BY PERSONNEL WITHOUT SHIELDING BUT WITH APPROPRIATE CLOTHING
4.73	HEAT INTENSITY IN AREAS WHERE EMERGENCY ACTIONS LASTING SEVERAL MINUTES MAY BE REQUIRED BY PERSONNEL WITHOUT SHIELDING BUT WITH APPROPRIATE CLOTHING.
1.58	VALUE OF AT DESIGN FLARE RELEASE AT ANY LOCATION WHERE PERSONNEL ARE CONTINUOUSLY EXPOSED.

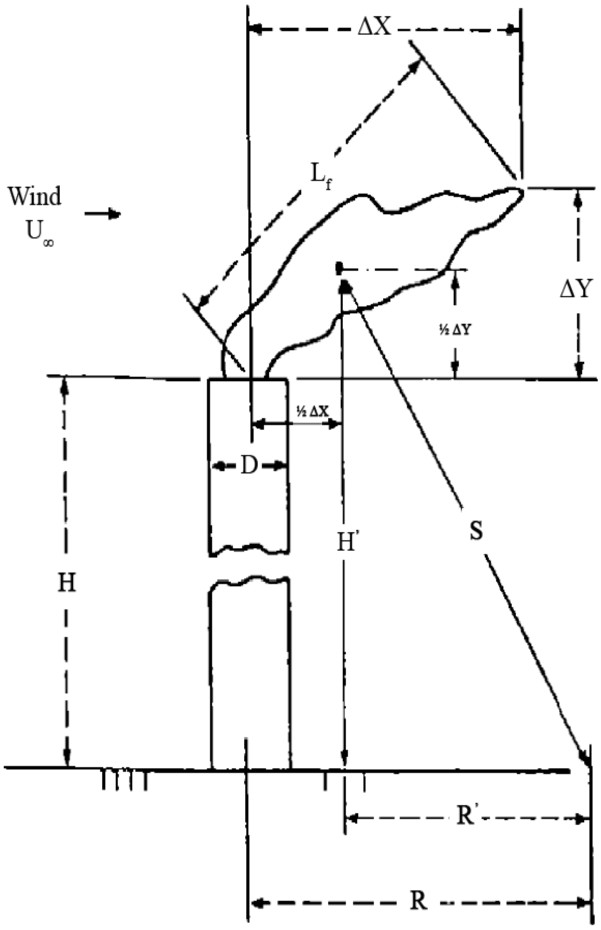

Fig. 8: Dimensional references for sizing a flare stack [1].

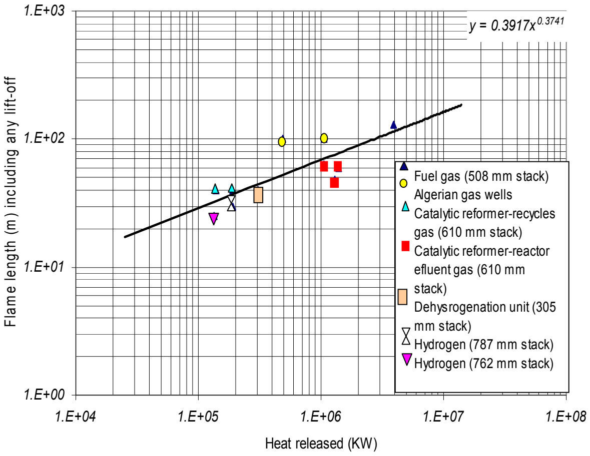

Fig. 9: Correlation between Lf & φ [1].

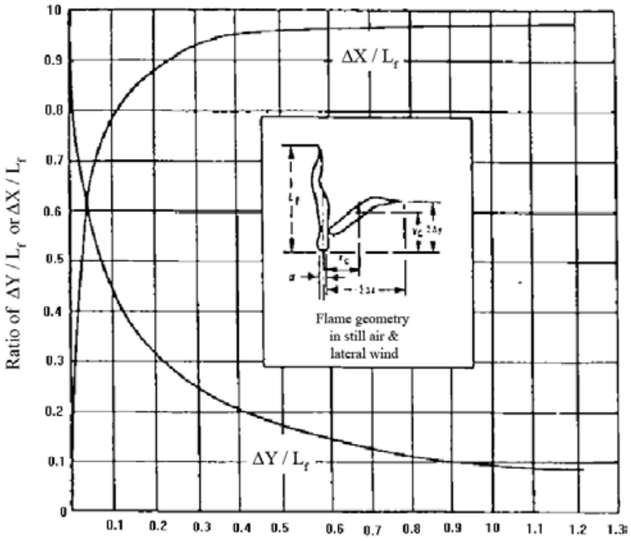

Fig. 10: correlation between Lf & ΔX, ΔY as a function of Ur [1].

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