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Multi-objective Genetic Algorithm Optimization of Natural Gas Pressure Drop Station Heaters Using the Entropy Generation Minimization Method

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ABSTRACT: In recent years, with the continuous growth of natural gas consumption in Iran, the number of pressure drop stations has increased significantly. In throttling valves of these stations, the temperature drop due to the Joule-Thomson effect causes the gas to hydrate, freeze the valves, and block the transmission path. Hence, about 14,000 indirect-fired water-bath heaters have a duty for preheating high-pressure gas before entering them. Unfortunately, the 30% average efficiency of indirectly fired water-bath heaters wastes nearly one billion cubic meters of processed natural gas every year, equivalent to a 400 MW power plant capacity. In this article, intending to optimize, indirect-fired water-bath heaters were modeled thermodynamically and thermo-economically, and three objective functions including thermal efficiency, entropy generation number, and wasted cost number are defined and the mathematical model was proposed in two scenarios. Then the model was solved based on the multi-objective genetic algorithm, using the entropy generation minimization method, and the Pareto optimal fronts of the scenarios were determined. The model implementation results with a deviation of less than ±10% compared to the results of a real sample indicate its acceptable performance. Based on the techno-economic justified results, it is possible to improve the efficiency of indirectly fired water-bath heaters between 48 and 55% depending on the gas volume flow rate. The relations, curves, and dimensionless groups obtained, can be used as a reference for the optimal design of indirect-fired water-bath heaters.

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1- Introduction

The IFWBHs, due to low thermal efficiency, annually waste a huge amount of processed natural gas in Iran. Although many researchers have investigated their optimization [1-3], three-objective optimization based on the Non-dominated Sorting Genetic Algorithm Technique (NSGA-II) using Entropy Generation Minimization (EGM) and Specific Exergy Costing Method (SPECO) methods have not been studied for IFWBHs so far.

2- Methodology

2- 1- Thermodynamic & Thermo-economic modeling

First, using energy, exergy, and cost balance equations, the problem is modeled in the framework of assumptions and technical-economic considerations, and the efficiency, losses, and cost measurement indicators are determined according to Eqs. (1) to (3), respectively:

$$\eta_{heater} = \eta_{bur} \cdot \left(\frac{\dot{Q}_{NG}}{\dot{Q}_{bur}} \right) \tag{1}$$

$$N_s = \frac{\sum \dot{S}_{gen}}{\dot{S}_{gen,MIN}} \quad ; \quad N_s \geq 1 \tag{2}$$

$$N_c = \frac{C_{rel}}{C_{rel,MIN}} \quad ; \quad N_c \geq 1 \tag{3}$$

2- 2- Mathematical modeling

Then, by selecting a set of 20 decision variables and simulating them to chromosome genes in the form of Eq. (4), three objective functions (5) to (7) are defined to calculate the chromosomes' fitnesses:

$$\begin{aligned} Chromosome\ IFWBH = \big[& EA\ BC\ \dot{V}_{NG}\ \dot{V}_{fuel}\ T_{bur,in} \\ & \ldots T_{hc,in}\ P_{hc,in}\ P_{tv,out}\ \eta_{bur}\ L_{sh} \\ & \ldots ID_{ft,i}\ ID_{hc,i}\ L_{wt,ft}\ L_{wt,hc}\ \varepsilon/D|_{ft} \\ & \ldots \varepsilon/D|_{hc}\ N_{pass,ft}\ N_{pass,hc}\ N_{path,ft}\ N_{path,hc} \big] \end{aligned} \tag{4}$$

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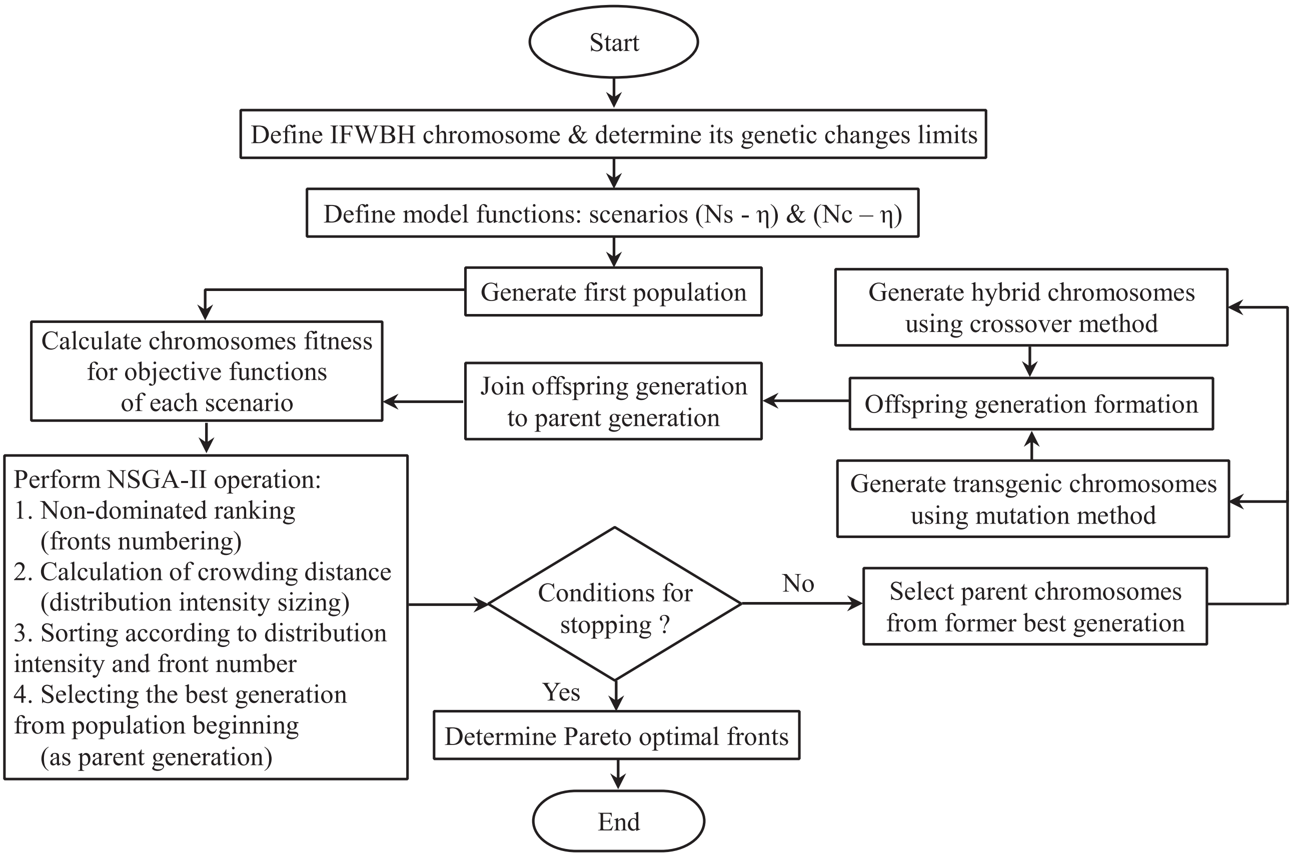

Fig. 1. NSGA-II flowchart used to solve the mathematical model of the problem

$$\eta = f_1(chromosome\ IFWBH) \tag{5}$$

$$N_s = f_2(chromosome\ IFWBH) \tag{6}$$

$$N_c = f_3(chromosome\ IFWBH) \tag{7}$$

These functions together with a set of equal and unequal constraints including thermodynamic and thermo-economic constants, operating limits, and scope of changes, make it possible to reach the space of feasible solutions to the problem. Next, in order to discover chromosomes that are able to compromise between contradictory fitnesses, the NSGA-II technique is used according to the flowchart shown in Fig. 1 and the setting parameters of Table 1.

3- Results and Discussion

Using the geometric parameters of an indirect-fired water-bath heater (IFWBH) sample manufactured by Oil, Gas, and Industrial (OGI) Process Equipment Incorporated [4] and the thermodynamic and thermo-physical parameters of reference [5] as real initial guesses, It was prepared more suitable first generation chromosomes in order to improve the sequence of convergent solutions in random iterations. Thus, the model

Table 1. The setting parameters of the proposed NSGA-II

Parameters	Symbols	Values
population size	*npop*	50
Probability of crossover	*pc*	0.7
Probability of mutation	*pm*	0.4
Mutation strength	*ms*	0.02
maximum of iteration	*maxiter*	100

was solved by simultaneously using Engineering Equation Solver (EES) and MATLAB software with parameters setting.Finally, Pareto optimal fronts for each of the proposed scenarios, determination, and optimal structural and process solutions of the IFWBH were introduced in the form of dimensionless groups. Based on the results, improving the thermal efficiency of IFWBHs in proportion to the gas flow passing through the heating coil is technically and economically justified in the range between 48 and 55%, and the total annual cost (Fig. 2) and the burner thermal capacity (Fig. 3) are within the limit of (), a function of thermal efficiency and gas flow rate, and outside this range, they depend on only one of the two.

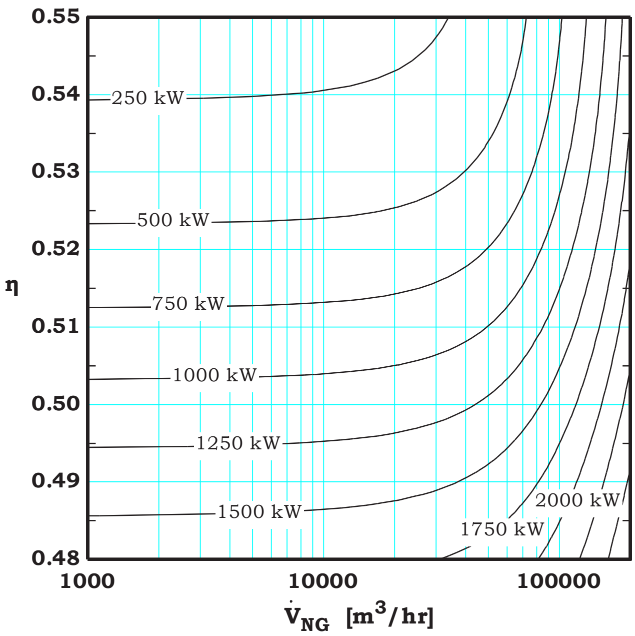

Fig. 2. Optimal Total Annual Cost of IFWBH

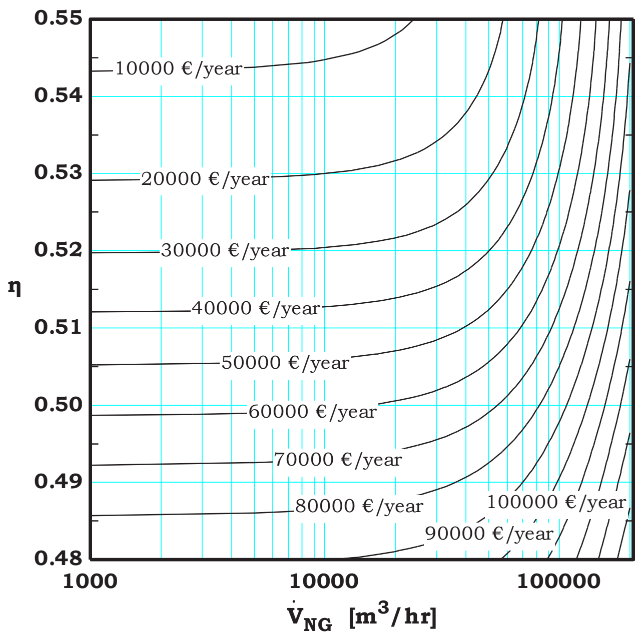

Fig. 3. Optimal Capacity of IFWBH Burner

4- Conclusions

The results show that for flow rates higher than 100,000 m^3/hr, the thermal efficiency is almost constant, despite the increase in the total annual cost and the burner thermal capacity. Meanwhile, for flow rates of less than 10,000 m^3/hr, for each one percent increase in thermal efficiency, about 10,000 € will be saved in the total annual cost and about 250 kW in the burner thermal capacity of IFWBHs.

Nomenclature

	Variables	Subscripts	
BC	Brine concentration, (%)	*bur*	*Burner*
C	Cost, (€)	*ft*	*Fire tube*
EA	Excess air, (%)	*hc*	*Heat coil*
ID	Inner diameter, (m)	*in*	*Inlet*
L	Length, (m)	*MIN*	*Minimum*
N	Number of pipes	*NG*	*Natural gas*
N_c	Wasted cost number	*out*	*Outlet*
N_s	Entropy generation number	*pass*	*Tube pass*
P	Pressure, (kPa)	*path*	*Tube path*
$\dot{Q}$	Thermal power, (kW)	*rel*	*Relative*
$\dot{S}_{gen}$	Entropy generation, (kW/K)	*sh*	*Shell*
T	Temperature, (°C)	*tv*	*Throttling valve*
$\dot{V}$	Volumetric flow rate, (m^3/hr)	*wt*	*Wall thickness*
ε/D	Relative roughness		
η	Thermal efficiency		

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