Energy waste reduction in central heating systems by new type of expansion tank

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In this study, a focus on geometry elements is taking place with open expansion tanks (OETs) to reduce the energy loss in the system. A new model based on the inlet and outlet flow control in the tank is developed by a semi-spiral coil. A fully numerical comparison of the proposed new OET and the conventional system is done in assistance with Computational Fluid Dynamic (CFD) modeling that has been utilized by the QuickerSim CFD toolbox. In order to approve the data, an experimental setup was installed in the laboratory, which includes: three types of OETs (conventional, optimized twin container, and optimized by the coil). Finally, the economic analysis of the new tank design has been performed. The Net Present Value (NPV) in all the three scenarios (international, without subsidy and with subsidy) for optimized models is more than zero and Internal Rate of Return (IRR) is concluded 38%, 113.3% 303%, respectively. Furthermore, the value of the Simple Payback (SPB) is half a year accordingly in the international energy price calculation based scenario. The results demonstrate the proposed OET that uses a coil, avoids the energy losses as much as possible. As an overall achievement, the energy losses in the OET with the coil are reduced in the range of 80% to 95%. Additionally, replacement of the conventional models by the new proposed design results in the annual energy saving of 857.1 cubic meters of natural gas per household.

keywords: *Open Expansion Tank (OET); Optimized OET with the coil; Computational Fluid Dynamic (CFD); Techno-economic analysis.*

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1. INTRODUCTION

In single-phase, natural circulation loops, expansion tanks play an important role. Expansion tanks are provided in closed systems to perform several tasks. The first purpose is to reduce the effects of pressure on the water volume as water density changes with temperature. Keeping a positive gauge pressure in all parts of the system is the second effect of the expansion tank to prevent air from leaking into the system. Finally, the expansion tank provides a source of makeup water and compensates the water lost when a leakage happens within the system [1].

The role of the expansion tank in loop dynamics has been investigated experimentally in a rectangular single-phase natural circulation loop by Kumar Naveen et al. [2]. Finding the relation between the expansion tank and the thermal hydraulic behavior of these loops was the main goal of this research. Based on their results, there is a significant amount of heat exchange between the main loop fluid and the expansion tank fluid. Expansion tanks are also considered for non-residential applications. In a research that has been done by M. Farzaneh-Gord et al. [3], a combined system, including a heat exchanger, a solar collector and expansion tank is proposed to prevent gas hydrate forming in natural gas.

The thermo-siphon phenomenon within the open expansion tanks (OETs) is based on the density gradient which is taking place between parts of a vertical pipe [4]. In a thermo-siphon system, there is no need to use a pump for the circulation of the fluid. In other words, the difference in rated pressure between height level of the pipe is solely adequate for fluid circulation. It should be noted that flow in a thermo-siphon system is laminar, so the application of the Bernoulli equations for the system is

Fig. 1. OET Heat losing in winter

available to find out rendered velocity and flow rates [5]. In order to consider the possibility of the energy loss reduction in the expansion tanks, some research studies have been carried out [6–8]. In the previous research which conducted before, a new insider tank (optimized OET with twin container) was designed to shoot the losses in energy, as a target [4]. In relation to this issue, Iranian fuel conservation company (IFCO) has planned a long-term research program whose final results have been published [9]. All types of OETs that locally are manufactured in Iran have been studied and some corrective modifications have been recommended for their improvement. Despite the previous study, there is still a lack of fundamental understanding of heat losses from these designs. In this respect, some attempts are made by one of the producers of OETs to produce a two-layer polyurethane-aided insulated tank, which is supported by the IFCO grants [9]. The interesting subjects in these studies include the resumption of heat, reconstruction of OET by considering double-layer tank requirement and reusing the gathered steam in the upper section of these tanks. Nevertheless, these issues have not been assessed with meticulous attention. Based on the issues which mentioned above, there are some weaknesses in OETs' design that can be summarized as follows:

- Intensive energy consumption as a result of considerable energy losses [4];
- Lack of proper insulation [10];
- Partial freezing regarding drops in dew point during winter case operation [11].

The conventional OETs that are usually applied in CENTRAL HEATING systems are presented in Fig.1. They are normally cylindrical, and their body often is made of metals including galvanized steel, aluminum and also fiberglass. The major defects of open expansion tanks are the huge energy loss, partial freezing inside OET, inappropriate moisture barrier, and improper steam sealing for an opening between the door and body.

The simple structure of OETs and inappropriate thermal insulation cause a great value of energy loss that won't be ignored. Undoubtedly, this defect is the most severe and crucial problem with these tanks.

The simulations considering the QuickerSim CFD Toolbox which uses the FVM method (Finite Volume Method) have been implemented by employing different design ideas and using the outputs to achieve the best design. As an outline of this research, the weaknesses of conventional OETs design were achieved, and then the novel scenarios were formularized. In each of the proposed scenarios, the focus was on the variations in temperature profile, velocity vector profile within the tank and the released heat energy from the tank body to the surrounding.

In this study, a focus on geometry and elements is taking place with OETs to reduce the energy loss in the system. Thus, the overall infrastructure of OETs, in relation to materials, geometry & water nozzle positions has been revised. To determine the concept of the new OET design, CFD open-source-code software has been used for simulation. Afterwards, by auditing the most permanent design in the experiment and analyzing the collected data, the amount of decreasing energy losses in the new optimized tank has been assayed. Finally, the economic analysis of the new tank design has been performed and compared with the presently used models regarding the increased construction cost and reduced heat loss expenses on the proposed model.

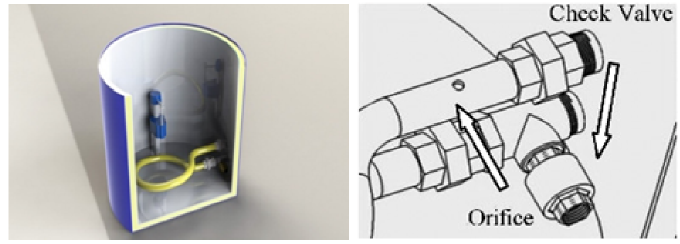

Fig. 2. (a): Optimized open expansion tank with coil and (b): Installed check valve and orifice on the Input and Output paths

2. SIMULATIONS & RESULTS

A. Description of the optimized OET with coil configuration

Since the proposed design is completely innovative and based on the experimental investigation, this section gives some technical details about the new structure. This model works on the basis of the inlet and outlet flow control in the tank. It leads to temperature reduction inside the tank and subsequently causes the energy loss reduction. In this innovative design, the inlet and outlet pipes are attached by a coil. The installed coil inside the tank controls water circulation, so the amount of high-temperature water is limited to the volume of the coil consequently. It leads to a lower average temperature in the whole tank and thereby reduces the temperature on the surface of the body, which means the lower heat transfer to the environment and substantial amount of energy saving in this way. An orifice is mounted at the top of the coil to maintain the pressure inside the tank at an atmospheric level. Moreover, when the water volume changes due to the increase in temperature in the CENTRAL HEATING system, the excess water flows through this orifice to level the volume reduction of the system. A view of this system is presented in Fig. 2. As demonstrated in Fig. 2(b), the orifice diameter is accurately adjusted according to the tank volume.

Installing a check valve at the lower section of the internal container avoids any leakage within the system and subsequently, the water rapidly is provided in the central heating system. In this situation, the water can only flow from the tank to the coil. Indeed, the static pressure within the pipe system will be decreased compared to the static pressure in the tank, even if there is an inconsiderable amount of leakage within the central heating system. So, the check valve lets the water to flow into the pipe and adjusts the flow when the central heating system requires the make-up water.

B. CFD modeling of optimized OET with coil

The final results of CFD approach and various views of temperature contours for this optimized design are shown in Figs. 3 and

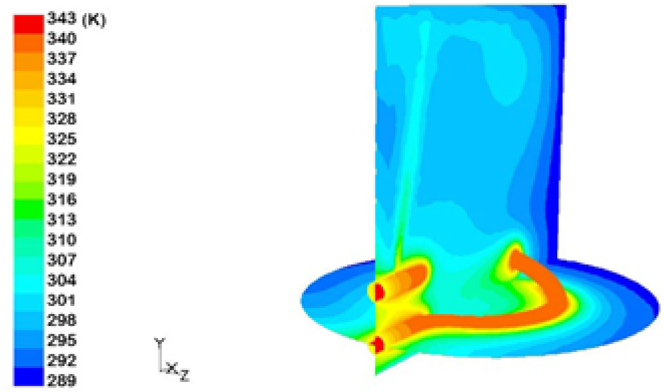

Fig. 3. Temperature contour around the coil of second new model of OET

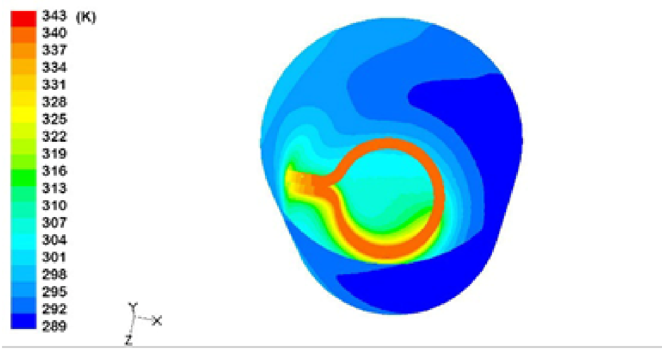

Fig. 4. Temperature contours that related to external wall surfaces in second new model of OET

4.

In Table 1, the wasted heat and temperature average for optimized OET with coil are reported.

C. Comparison of the performance contributed to different designs

The heat losses have been calculated for both the conventional OET and the new suggested designs by CFD tool. To compare the results, the tank volume and conditions are considered similarly for all calculations, whereas the surrounding temperatures are assumed Tehran's province temperature. In order to determine the tank input water temperature, the set-point temperature of the central heating system is selected as a reference temperature. Because this set-point temperature depends on the seasons of the year (55 up to 65 ° C), the seasons of the year are classified into warm and cold seasons. The months of May to October are considered in the warm season so that the set-point temperature sets at 50 °C. On the other hand, the cold season, which the set-point temperature is 82 °C, include months of November to April. Based on the observations, the heat loss from the tank to surrounding would decrease around 90%, if isolation is considered according to the new design. In contrast, the heat loss solely drops about 66% if the isolation is ignored. Fig. 5 explains a comparison of the energy performance regarding the insulation application. As it is shown in Fig. 5, the insulation is a proper add-on especially in the "optimized OET with coil" application.

Table 1. Heat losses and average temperature in Optimized OET with coil

Heat loss (W)			Qtotal	Average temperature at (K)		
Wall1	Wall2	Wall3		Tin	Tout	Touter surface
50.05	30.99	42.39	184	355.15	354.2	308.41

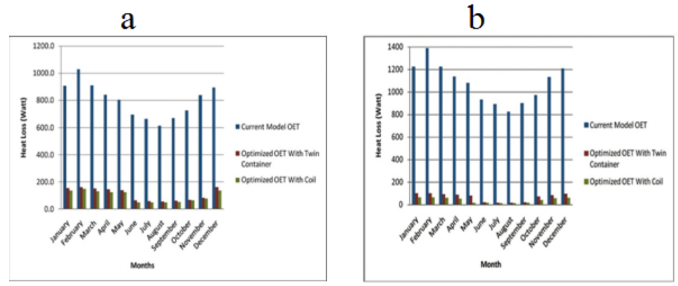

Fig. 5. Heat losses Comparison between different models of OET (a): without insulation and (b): with insulation during one year [4: Partly associated]

Fig. 6. OET Open expansion tanks pilot in the energy auditing lab. (1) Optimized model by the coil. (2) Conventional model. (3) Optimized Twin container

3. ENERGY QUANTIFICATION (APPROACH AND PROCEDURES)

As mentioned before, the amount of energy loss is calculated by CFD. So, it is necessary to manufacture a system on the basis of the new model. In order to validate the simulating data, an experimental setup was installed in the laboratory, which includes: three types of the open expansion tank (conventional, optimized twin container and optimized by the coil). Each tank capacity is considered 100 liters. Since the main purpose of this study is the energy loss calculation, the test results are analyzed and energy audited. It is crucial to keep the equal volume of water in each tank similar to the volume used in actual applications to certify the accuracy of the measurements. An electric heater was used to warm the required water for the pilot and the outlet water temperature was controlled by a thermostat. Fig. 6 illustrates the OETs experimental setup, which is implemented for experimental measurements.

The water is circulated by an inline circulator pump. In order to regulate the inlet and outlet water flow rate, an adjustable globe valve was installed and the flow rate was measured by the ultrasonic flow meter. To accurately control the water level inside the tank, the inside wall of the tank was calibrated. By using digital data gathering system, T_{in} and T_{out} profile changes were documented at the whole time of the experiment. The wind was simulated by a fan and the wind velocity around the tank

Table 2. Measurement characteristics

No	Item	Recording period	unit	Equipment
1	T_{in} & T_{out}	Every 10 min	°C	Testo 175-T3
2	Flow rate	continuous	Ml/s	ultrasonic flow rate meter
3	Wind speed	3 times	m/s	Testo- multi function-345
4	Tambient	Every 5 min	°C	Testo175-T2
5	Tinner	Every 5 min	°C	Testo175-T2
6	Temperature	-	-	TVS system Testo 880

Fig. 7. TVS devices in order to temperature contour auditing

was measured. The exact recording temperature inside the tank is very important because the temperature decreasing can prove the superiority of this new design rather than the conventional design. Table 2 indicates the measurement characteristics.

The flow rate was selected at 50 ml/s. Since the accurate measurement of the water temperature inside the tank is very important, the "Testo 175-T3" system, that is portable monitoring equipment, was used to record the temperature variations of the inlet and outlet water every 10 minutes. "Testo175- T2" and a probe were used to record the ambient temperature every five minutes. In order to simulate the ambient air temperature, the air-conditioning system installed in the laboratory was adjusted between 15 to 30 °C. The Testo 880 thermal video system (TVS) was employed to monitor the constant temperature line positions (temperature contours). Using the related computational results variations in different parts of the tank, the appropriate positions of isothermal lines in each experimental pilot were identified. In order to proper clarifications, see Figs. 7 and 8.

In Fig. 9 the obtained temperature contours for the conventional design is depicted, while Fig. 10 illustrates the temperature contours of the optimized design with coil OETs that is proposed in this study.

Fig. 8. Wind speed measurement around OET

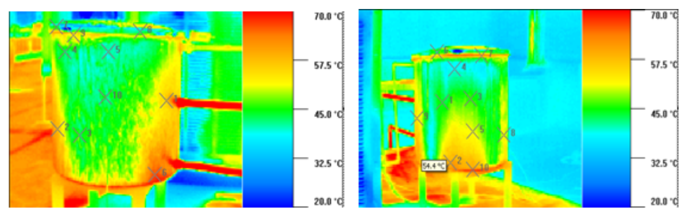

Fig. 9. Temperature Contour of Conventional OET

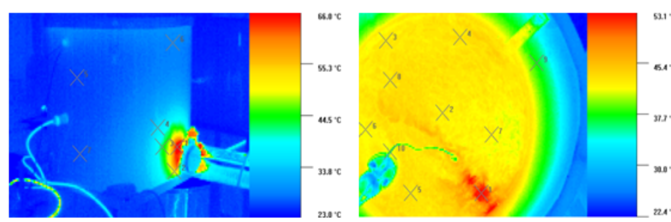

Fig. 10. Temperature Contour of Optimized OET Coil

4. ENERGY AUDITING CONTRIBUTED TO ANALYTICAL APPROACH

The main target in this section is to analyze the outcomes which are obtained experimentally regards to the energy auditing procedure in relation to the calculation results. In proper comparison, the dropped data are not considered [12].

A transformation function is deployed to synchronize the experimental and theoretical results for the purpose of scale up. The function would assist to validate the results of CFD based on the experiments [13].

$$[Temperature_{CFD}] \times [Function_{Transformation}] = [Temperature_{Actual}] \quad (1)$$

To find the mentioned function for the measurement scenarios, it is proposed to calculate the functional matrices demon-

Table 3. Energy auditing result

-	Item	Theoretical	Actual	Unit
current model OET	T_{in}	63.45	63.5	°C
	T_{out}	57.4	58.5	°C
	$T_{ambient}$	33.23	33.2	°C
	T_{inner}	58.11	59.5	°C
	$T_{surface}$	58.03	59.4	°C
	Q (Total)	289.76	354	W
Optimized OET with twin container	T_{in}	51.5	51.5	°C
	T_{out}	51.45	50.9	°C
	$T_{ambient}$	25	25	°C
	T_{inner}	46	47.3	°C
	$T_{surface}$	26	29.1	°C
	Q (Total)	9.2	51.5	W
Optimized OET with coil	T_{in}	68.6	68.6	°C
	T_{out}	68.5	63.2	°C
	$T_{ambient}$	27.8	27.8	°C
	T_{inner}	57	50.2	°C
	$T_{surface}$	29.7	30.1	°C
	Q (Total)	11.5	18.1	W

strated in (1). The function in Equation 1 is generated in accordance with the matrices shown in Equation (2).

$$\det \begin{bmatrix} x_1 & 0 & 0 & 0 & \dots & n \\ 0 & x_2 & 0 & 0 & 0 & 0 \\ 0 & 0 & x_3 & 0 & 0 & 0 \\ 0 & 0 & 0 & x_4 & 0 & 0 \\ \dots & 0 & 0 & 0 & x_5 & 0 \\ n & 0 & 0 & 0 & 0 & x_n \end{bmatrix}_{n\times n} = Conversion \quad Function \tag{2}$$

According to the mentioned method for the heat energy loss, belongs to the walls of the tank, a function same as (1 can be applied, in (3 as follows:

$$Conversion_{Coefficient} = (Q_{Actual}/Q_{Theoretical}) \tag{3}$$

The result which is gained through the energy auditing and measurement of the water temperature, contributed to the inside of the tank are shown in Table 3, as follow:

To calculate the real quantitative transformation coefficients, the selected temperatures, which are stated in Table 3 and incorporate them into the matrix (4).

Table 4. Comparison of thermal conversion coefficient and heat loss conversion coefficient in different parts of optimized OET with coil

	location	Wall 1	Wall 2	Wall 3
Conventional model OET	Thermal conversion coefficient	1.014	1.16	1.18
	heat loss conversion coefficient	1.43	1.003	1.033
Optimized OET with twin container	Thermal conversion coefficient	0.266	0.264	0.133
	heat loss conversion coefficient	3.7	1.07	1.13
Optimized OET with coil	Thermal conversion coefficient	1.132	0.877	1.043
	heat loss conversion coefficient	2.395	1.102	1.236

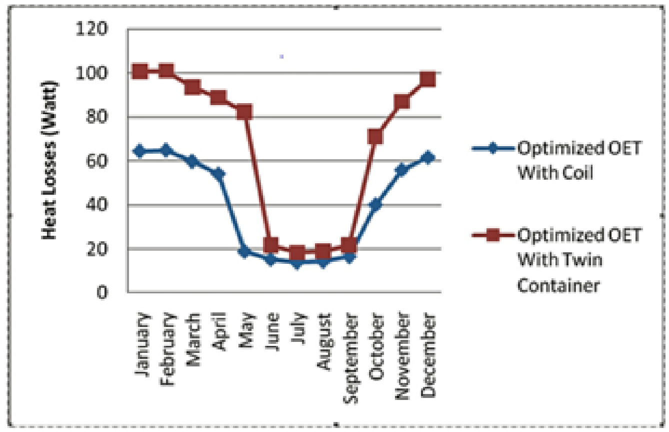

Fig. 11. Annual heat losses comparison between optimized open expansion tanks

$$\begin{bmatrix} A_1 & B_1 & C_1 & D_1 & E_1 & \dots \end{bmatrix}_{n\times 1} \times \begin{bmatrix} x_1 & 0 & 0 & 0 & \dots & n \\ 0 & x_2 & 0 & 0 & 0 & 0 \\ 0 & 0 & x_3 & 0 & 0 & 0 \\ 0 & 0 & 0 & x_4 & 0 & 0 \\ \dots & 0 & 0 & 0 & x_5 & 0 \\ n & 0 & 0 & 0 & 0 & x_n \end{bmatrix}_{n\times n} = \begin{bmatrix} A_2 & B_2 & C_2 & D_2 & E_2 & \dots \end{bmatrix}_{n\times 1} \tag{4}$$

A. Investigation of results on OETs, Twin container the optimized model with coil

It should be considered that the gained results through the energy auditing and measurement of the water temperature inside the coil tanks validate the theoretical model, as shown in Table 4. Respecting the calculation of energy loss, the transformation functions can be modified contributed to the gained results regarding the theoretical calculations. Hence, these functions were multiplied by results obtained from the numerical calculations.

Fig. 11 depicts the comparison between energy wastes for two new designs including the OET with coil and two containers in the annual measurement period. In the second model, this level shows a 35% reduction of heat losses.

Detail comparison of the energy loss values among the new proposed design (optimized OET with coil) and two other types of OETs are presented monthly in Table 5.

Table 5. Monthly heat losses comparison between current models OET and optimized OET

Month	Heat losses for different types of OET (Watt)		
	Conventional	Optimized with Twin Container	Optimized with Coil
January	1224.5	100.8	64.5
February	1390.4	100.9	64.9
March	1222.7	93.6	59.8
April	1135.8	88.8	54.1
May	1080.1	82.2	18.7
June	933.3	21.6	15.1
July	894.3	18.2	13.7
August	823.3	18.8	14.2
September	900.9	21.6	16.4
October	973.9	71.1	40
November	1131.3	88	55.9
December	1209	97.2	61.6

Table 6. Annual Energy saving of optimized OET

Optimized OET with	Annual (Btu)(m^3)	Natural Gas (m^3)
Twin Container	30274254	857.1
Coil	30937167	875.89

5. ECONOMIC ASSESSMENT

As explained in previous sections, a significant level of energy and heat loss, those have been encountered in the system, is prevented. Hence, a far better economic viewpoint is predicted. To find the total economic benefit obtained due to this variation, the two new models were then investigated separately in terms of economic considerations. The Level of annual energy saving result by the application of the two new proposed models is given in Table 6.

The Level of the annual financial saving due to this modification and based on the natural gas consumption is given as follows: By taking into consideration the Iranian government's subsidy, final national price international market of a cubic meters of natural gas is 1, 6.9 & 23 Cent(s) in 2009, respectively [14]. The financial profit gained through the saving energy (R) is computed with regard to the prices of natural gases consumption [15]. The interest rate is 17% and also the annual growth rate is 13% (according to the third and fourth development programs of the government). Based on the experimental considerations, the life cycle is estimated 15 years. To fulfill the economic assessment of the system, all the expenses and incomes are adopted for annual, added to the value cost. The coefficient of Gradient Present Worth (GPW) is used to determine the present value difference when the annual growth of energy rate is applied. Equation (refeq.5) depicts GPW coefficient [16].

$$GPW = \frac{\frac{1+e}{1+i} * [1 - [\frac{1+e}{1+i}]^n]}{1 - \frac{1+e}{1+i}} = 11.495 \quad (5)$$

The total annual income for energy saving is given by P in Table 7 and all the investment expenditures are given by Δk_0 [17].

$$P = R \times GPW \quad (6)$$

Table 7. Investment costs based on base Δk_0

No	Description	Investment Cost ($)
1	Buying new OET cost	70
2	Installation and initial cost	100
3	Maintenance cost	107.18
4	Accessories and consumable parts cost	76.82
5	Total cost of investment (k0)	983,998

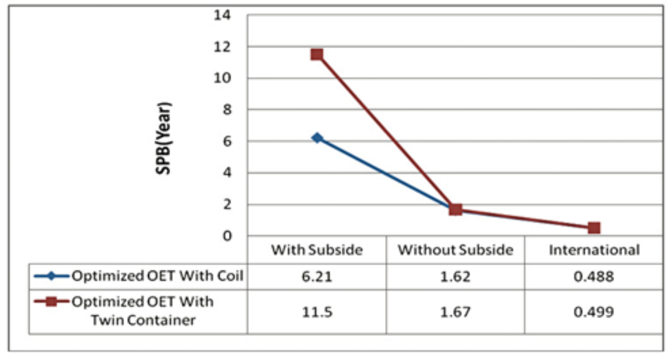

Fig. 12. SPB based on different prices of natural gas

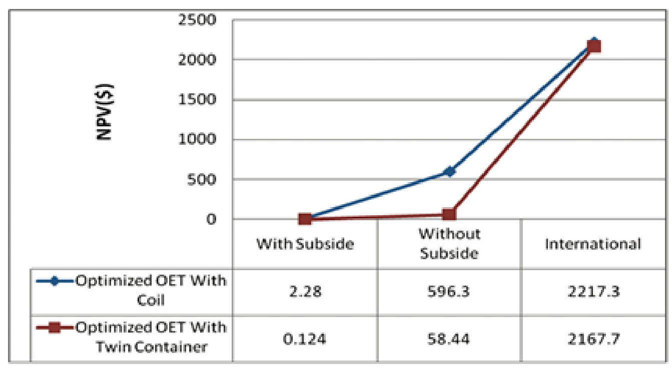

Fig. 13. NPV variation based on different prices of natural gas

A. SPB computing

According to the SPB, one can simply approximate the return of investment, SPB is determined based on the different prices of natural gas [17].

$$SPB = \frac{\Delta K_o}{R} \quad (7)$$

The results are presented in Fig. 12.

B. NPV computation

Subsequent to the calculation of costs and incomes, it is necessary to find NPV. This is an essential factor in economic assessment, which has to be more than zero. It should be mentioned that NPV is obtained by means of (8) [17]:

$$NPV = R.GPW - \Delta K_0 \quad (8)$$

The results are presented in Fig. 13.

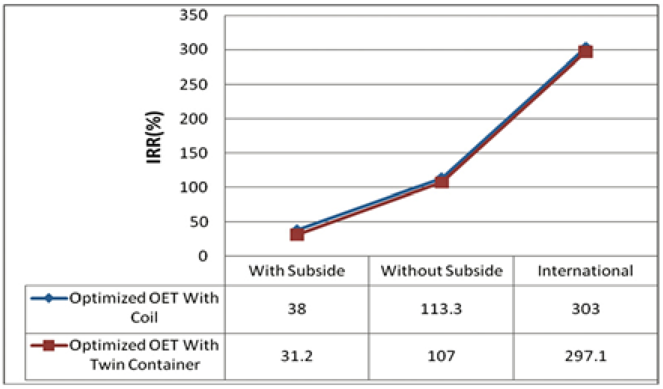

Fig. 14. IRR variation based on different prices of natural gas

Table 8. Economic Assessment results based on different natural gas prices

Optimized OET	Index	International	Without subsidy	With subsidy
	cents/m3	23	6.9	1
Twin Container	R ($)	1971330	591399	85710
	P ($)	22660438	6708131	985236
	SPB(Year)	0.499	1.67	11.5
	NPV ($)	21676440	584413	1238
	IRR (%)	297.1	107	31.2
Coil	R ($)	2014547	604364.1	87589
	P ($)	23157217.8	6947165.3	1006836
	SPB(Year)	0.488	1.62	6.21
	NPV ($)	22173219	5963167	22838
	IRR (%)	303	113.3	38

C. IRR computing

In the next step of economic assessment, IRR is required. By the aid of the (9), for IRR, this level is obtained. Regarding this formula, the annual level of saving on energy can be determined as follows. The computation loop will start with$NPV = 0$ assumption [18]:

$$\begin{aligned} &\sum_{j=i}^{j=n} \frac{R*(1+i)^{-j}*(1+e)^{-j}}{(1+IRR)^{j}} - \Delta K_o = 0 \\ &\sum_{j=i}^{j=15} \frac{R_j*(1+0.17)^{j}*(1+0.13)^{j}}{(1+IRR)^{j}} - 983998 = 0 \end{aligned} \quad \textbf{(9)}$$

By using trial and error and interpolation, the IRR will be rendered which is calculated based on the natural gas prices, given in Fig. 14.

In Table 8, the values of the SPB, NPV, and IRR for optimized OET models have been presented based on the natural gas prices:

6. CONCLUSION

In this research, a novel OET design that uses a coil is proposed to avoid the energy losses as much as possible. In details, the energy losses in the OET with the coil are reduced to 80%, if this new design implements instead of the other models. However, by using the isolated case, the energy saving will be improved up to 95%. Compared with twin container, the presented design has the following advantages:

- Lower volume in water container to save the energy storage;
- Easier control of the flow rate variable as a control parameter;
- More adaptable configurations within the heat exchanger similarities and formulations.

From the economic point of view, the replacement of the conventional models by the new design that proposes in this study, results in the annual energy saving of 857.1 cubic meters of natural gas per household. So, including the environmental aspects, the optimized OET with the coil is capable to save the energy in large scales and subsequently reduces the consumption of fossil fuels.

REFERENCES

1. Sanfiorenzo, A.B. (2013). Cooling system design tool for rapid development and analysis of chilled water systems aboard U.S. Navy surface ships. (Master dissertation), Massachusetts Institute of Technology. Retrieved from http://hdl.handle.net/10945/40254.

2. Naveen, K., Iyer, K.N., Doshi, J.B., Vijayan, P.K. (2015). Investigations on single-phase natural circulation loop dynamics. Part 3: Role of expansion tank. Progress in Nuclear Energy, 78, 65-79.

3. Farzaneh-Gord, M., Arabkoohsar, A., Deymi Dasht-bayaz, M., Machado, L., Koury, R.N.N. (2014). Energy and exergy analysis of natural gas pressure reduction points equipped with solar heat and controllable heaters. Renewable Energy, 72, 258-270.

4. Mohsenian, H., Ghadamian, H., Hamidi, A. A., Alizad, K. (2015). Expansion Tank Structural Reconstruction for Central Heating Systems with Re-Engineering Consideration and Energetic Losses Minimization. Proceedings of the ASME 2015 Power and Energy Conversion Conference, San Diego, California, USA.

5. Incropera, F.P., DeWitt, D.P. (1996). Introduction To Heat Transfer (3rd ed.). JOHN WILEY SONS.

6. Shafiee, M.E., Berglund, A., Berglund, E.Z., Brill Jr. E.D., Mahinthakumar, G. (2016). Parallel Evolutionary Algorithm for Designing Water Distribution Networks to Minimize Background Leakage. Journal of Water Resources Planning and Management, 142(5), C4015007-1-C4015007-7.

7. Luzzia, L., Misaleb, M., Deviab, F., Pinia, A., Cauzzia, M.T., Fanalea, F., Cammi, A. (2016). Assessment of analytical and numerical models on experimental data for the study of single-phase natural circulation dynamics in a vertical loop. Chemical Engineering Science, doi: http://dx.doi.org/10.1016/j.ces.2016.12.058

8. Cammi A., Cauzzi M., Luzzi L., Pini A. (2016). DYNASTY: AN EXPERIMENTAL LOOP FOR THE STUDY OF NATURAL CIRCULATION WITH INTERNALLY HEATED FLUIDS. 12th International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics, Malaga, Spain.

9. Iranian Fuel Conservation Company (IFCO). (2004). Optimization of manufacturing of open expansion tanks. http://ifco.ir/index.php/other/item/747-enbesat.

10. Steven T. Taylor, P.E. (2016). The Fundamentals of Expansion Tanks. ASHRAE Journal, 60-66.

11. Chaturvedi, S.K., Chen, D.T., Kheireddine, A. (1998). Thermal performance of a variable capacity direct expansion solar-assisted heat pump. Energy Conversion and Management, 39(3-4), 181-191.

12. Humann, A. (1983). Handbook of energy audits, Georgia, USA.

13. Thumann, A., Niehus, T., Younger, W. J. (2012). Handbook of energy audits, Fairmont Press.

14. Izadyar, N., Ghadamian, H., Ong, H.C., Tong, C.W., Shamshirband, S. (2015). Appraisal of the support vector machine to forecast residential heating demand for the District Heating System based on the monthly overall natural gas consumption. Journal of Energy, 93, 1558-1567.

15. Izadyar, N., Ong, H. C., Shamshirband, S., Ghadamian, H., Tong, C. W. (2015). Intelligent forecasting of residential heating demand for the District Heating System based on the monthly overall natural gas consumption. International Journal of Energy and Buildings, 104, 208-214.

16. Holman, J. P. (1997). Heat Transfer, McGraw-Hill, INC.

17. Gottschalk, C. M. (1996). Industrial Energy Conservation, CMG International Energy Consultancy, JOHN WILEY SONS.

18. Yaffey, M. (1992). Financial analysis for development: concepts and techniques, Clarendon Press - Oxford University Press, London.