Energy Economy for Dryer Unit in a Carpet Plant

*[1]Kemal Ermis, [2]Yasar Sen, [3]Nedim Sozbir and [4]H. Ibrahim Sarac
*[1]Faculty of Technology, Department of Mechanical Engineering, Sakarya University, Turkey
[2]Sapanca Vocational School, Department of Electrical and Energy, Sakarya University, Turkey
[3]Faculty of Engineering, Department of Mechanical Engineering, Sakarya University, Turkey
[4]Faculty of Engineering, Department of Mechanical Engineering, Kocaeli University, Turkey

Abstract

Machine carpets are special kind of Turkish products with worldwide fame. They occupy an important role in industry and %80 of carpets is manufactured in Gaziantep region in Turkey. More than a half of the total production is sold outside of Turkey because of its cultural value. In a carpet plant finishing department, spreaded glue on the base of carpet is dried by natural gas burn. In this process, total energy of 310815 kJ/m^{3}h is consumed and a huge amount of heat loss happens.

In this study, Authors propose a new vapour dryer system instead of using the drum's dryer system in the carpet drying process. Also they showed advantages and disadvantages of these systems according to basic criteria in this study. It was observed that 1295 $/per month saving has been obtained by using the discharge vapour instead of the natural gas burn dryer.

Key words: Energy economy, carpet, natural gas

1. Introduction

Carpet fabrication has become an important industrial development worldwide, similar to other technologically advanced process industries. There are many processes in the carpet industry. In these processes, drying has an important role: by this means, carpet can acquire their final texture, consistency and flexibility.

A few researchers are investigated carpet drying processes. Haghi [1] presented a study that is part of a more general attempt to analyze heat and mass transfer in carpet in terms of basic transfer mechanisms in order that a mathematical description of the overall process. Hangi described the effect of important parameters during drying process and the drying behaviour of carpet in a combined microwave and convective environment in his model. Francis and Wepfer [2] investigated the thermal characteristics of a continuous industrial drying process for semi-porous textile composites. Their model results of the continuous industrial drying process are compared to independent experimental temperature and global moisture content measurements taken in an operational industrial dryer. Lee *et al* [3] developed a transient two-dimensional

*Corresponding author: Address: Faculty of Technology, Department of Mechanical Engineering, Sakarya University, 54187, Sakarya TURKEY. E-mail address: ermis@sakarya.edu.tr, Phone: +902642956528

mathematical model to simulate the through-air frying process for tufted textile materials. They solved three non-linear differential equations in used numerical analysis by an implicit finite difference method. Ogulata [4] presented utilization of waste-heat recovery in textile drying by using a heat exchanger, recuperator. He calculated gained heat transfer rate of recuperator by increasing temperature of inlet air to dryer system. Cay *et al* [5] studied reveals energetic and exergetic analysis of a stenter system in a textile finishing factory based on actual operational data. They found the exergetic efficiencies of the stenter and hot oil boiler were found to be 28.7 and 34.7%, respectively, while the overall exergy efficiency of the system was obtained to be 34.4%. Also they [6] presented an exergetic approach for textile fabrics by exhaustion principle. Dennis and Buchanan [7] investigated tension effects during a commercial heat setting process through the analysis of the thermomechanical behavior of heat set nylon 6 carpet yarns. They showed a technique, analysis of the shrinkage force curves and their characteristic parameters, is capable of identifying subtle variations in fiber microstructure and therefore has significant applications to the identification of stress history differences in heat set fibers and yams. Akyol *et al* [8] studied drying behavior of viscose yarn bobbins was investigated experimentally to specify the optimum drying conditions and a drying model was proposed for simulation of drying.

Widespread methods of carpet drying all over the world are mostly convective methods requiring a lot of energy. Specific heat energy consumption increases, especially in the last period of the drying process when spreaded glue dry on the carpet is drying carpet. A very common method of drying of the glue is convective on the carpet drying.

Research activities in a carpet plant, Gaziantep, showed that 150 carpets with each 6 m^2 area pile been fabricated daily and during this process some heat loss has been determined. Heat energy loses at the finishing department in the carpet plant. In this unit, spreaded glue on the carpet base is dried by heat obtained from natural gas burn. This method causes to lose huge amount of heat during burning of natural gas and safety level of working environment decreases. Heating fire has radius of 1150 mm and length of 2500 mm and this causes losing of heat on drying process. During the usage of natural gas tube, 310815 kJ/m^3h of energy is consumed. In the same factory, vapour, has 4 bars, is applied to paint the blankets. %30 of the vapour is discharged to atmosphere without any handling. In the proposed system, discharged amount of the vapour is applied to cylinder and carpet is wrapped up to the outer surface of the cylinder. This leads an economical and safety dryer environment for the glue used on carpet base.

2. Carpet Production

Many steps pile been determined during the research activities in a carpet plant. Flow chart for the production process can be seen in Figure 1. Main raw material for the carpet manufacturing is thread provided from industry. These threads can be classified as pile yarn, weft yarn and warp yarn. Pile is the colorful thread, which forms the carpet pattern full and hairy surface. As a result of raw material used in carpets, it can be named as woolen or silky. Warp thread which stretches out vertically at the carpet base is a mixture of cotton and polyester. Jute thread is also mixture of cotton and polyester but it is thinner than warp thread. This thread composes the carpet base in width. Jute thread is moved cross inside warp thread in weaving machine. In each rub point, pile thread is driven perpendicular to the plane formed by Jute and warp threads.

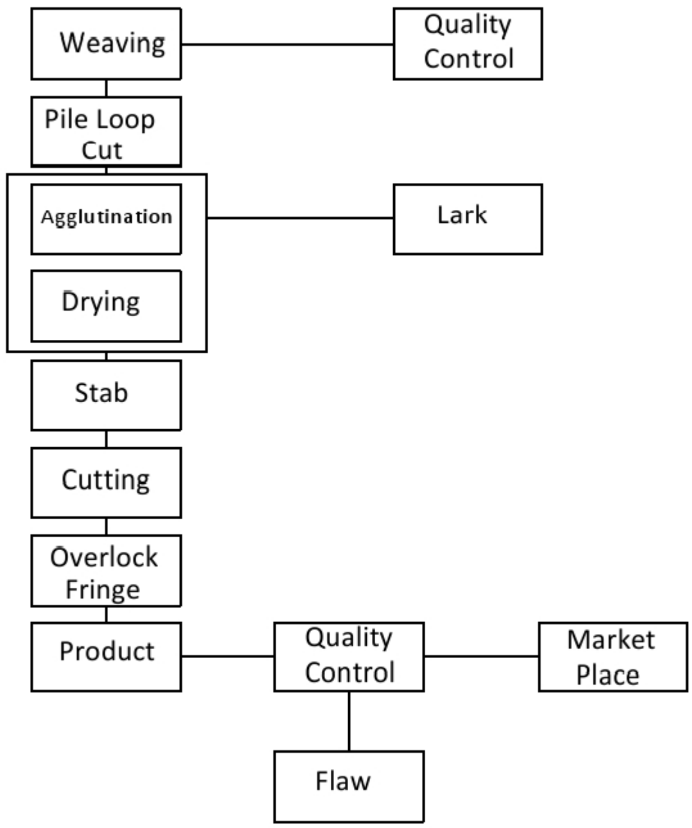

Figure 1. Carpet Manufacturing Flow

Weaving state of the carpet threads is illustrated in figure 2.

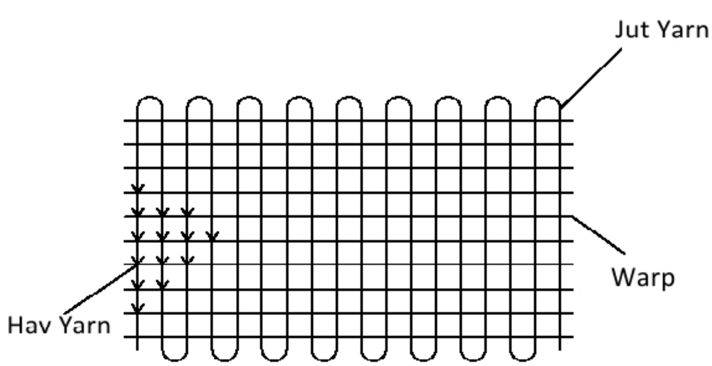

Figure 2. Order Carpet Yarn

2.1. Coil Wrap up Process

Pile and jute threads can be wrapped up to different coils in one piece, warp thread is wrapped up to 2.5 m long coils called as beaming so that they form the width of the carpet.

2.2. Weaving Process

Warp and jute coils are located inside weaving machine. Pile threads must be located inside the machine and their locations must be pre-determined because they provide the color and pattern for the carpet. Pile thread coils must come across because two carpets located face to face are weaved inside machine at the same time. Attaching the coils to the weaving machine is called as Caga Correspondingly warp and Jute threads are weaved as pileless carpets and rush mats. Face to face weaved two carpets can be manufactured by passing pile threads perpendicular to rush mat plane. After pile thread is weaved, face to face located carpets are divided into two pieces by a sharp cutting blade. This leads production of two carpets equally patterned and sized.

2.3. Pile Loop Cut Process

Two similar carpets manufactured in the weaving machine pile different base characteristics. One has rub and thread extensions and similar churns at the base side; however the other one has a clean base. Carpet with churns at the base side will be cleaned by blades and combs and then rolled up to store.

2.4. Finishing Department

Two processes pile been applied to rolled carpets inside the finishing department. First process is gluing the carpet base. Second one is drying the glue. Rolled carpet is entered inside the finishing department unit by a 50 mm diameter cylinder. Afterward each rub point is extended equally spaced by three cylinders with 80 mm diameter. Then carpet is processed by three cylinders with radiuses 50 mm, 80 mm and 120 mm respectively. The surface which will be glued is cleaned by a thin comb located between last two cylinders. Final step is the gluing process for the back of the carpet which done by four subsidiary cylinders (100 mm) and one main cylinder (250 mm). Carpet reaches to dryer unit after gluing. Pre-heating is applied to glued surface. After passing five cylinders, drying process is accomplished by the outer surface of a Drum with 1150 mm radius and 2520 mm length. Finally drying process is completed and the carpet is got out by a wooden cylinder with spines of 2 mm diameter and 12-13 mm length. Spines are placed with 10 mm space. Spiny cylinder has a function of moving the carpet and digging holes on the glued surface to avoid the carpet being extremely hard. Gluing and the drying processes are shown in figure 3.

2.5. Shearing, Cutting, Overedge and Fringe Sewing

A smooth surface is obtained when carpet surface is sheared from the shortest pile thread level. Carpet fringes are done overedge after blading. Fringe sewing is done before industry delivery.

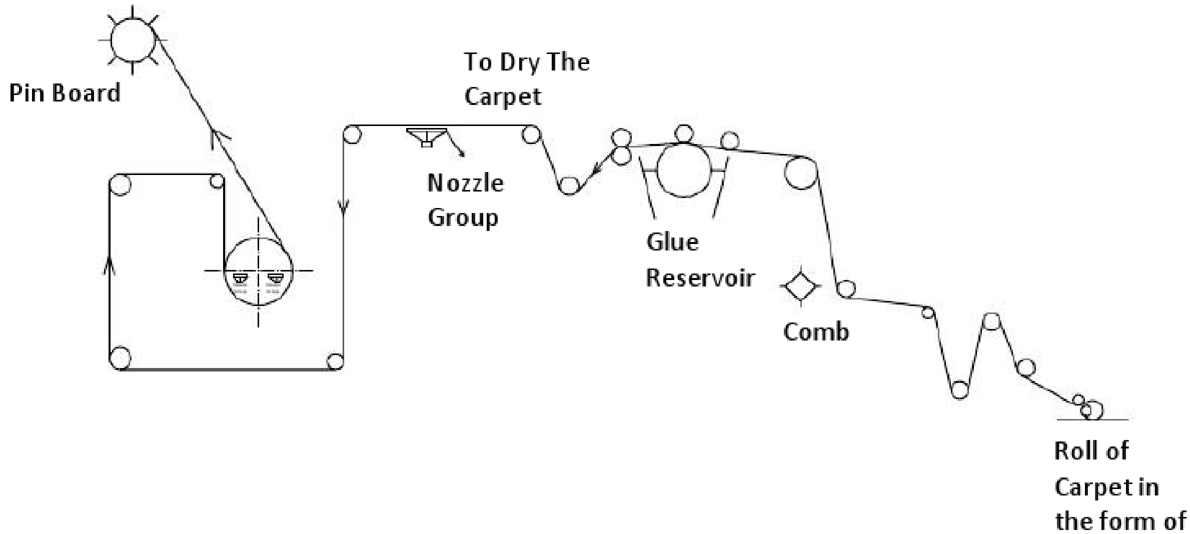

Figure 3. Glue and drying process

3. Energy Consumption on Drum's Dryer System

150 carpets, which pile 6 m^2 of area individually, can be dried in the carpet dryer department. Drying process can be applied in two steps. The heat required for pre-heating and drum part can be provided by the burn of natural gas. As seen in figure 3, series of nozzles are heating the metal plate in pre-heating and the carpet is heated while passing over this plate. This nozzle group is open to atmosphere. So the combustion products can be given to working environment. Heating nozzle groups are located on the both sides of dryer drum. The inner surface of the drum is heated when natural gas is burned inside nozzles. Both tip points of the nozzle are open to atmosphere and the combustion products can be thrown to environment. Enormous amount of heat loss happens inside pre-heating and drum units.

108.3 m^3 of natural gas is used in dryer unit for 12 hours of operating process. If lower heating value of natural gas is taken as 34441 kJ/m^3, total energy of Q_{nat} = 310815 kJ/h are consumed in dryer unit

4. Advantages and Disadvantages of Drum's Dryer System

The energy need of the dryer system is provided by the burn of natural gas in this system. As an advantage, initial investment cost is low, however operating cost is high. The disadvantages of systems operating by natural gas can be given as energy loss inside dryer unit is very high.

Compromises hazards for work safety and worker health because of the combustion products released to working environment due to lack of chimney system in half open atmosphere system.
Increased risk of fire inside factory because flame based drying is applied close to the combustible materials inside dryer unit.

High cost due to use of natural gas which is expensive to use and produce.

Degradation on drying process caused by non-homogenous heating related with nozzles located on certain points.

Enough heat isolation inside dryer unit can't be accomplished due to necessity of combustion product dismissing and natural gas burn inside drum nozzles.

Increment on labour cost due to high number of workers needed for continuity and safety of operating system.

Difficulties on system management and control related with high degree of risks and hazards on system operation.

5. Proposed New System by Vapour

It is determined that a 4 bar scotch vapour boiler is currently operating in blanket unit to paint blankets. The thermal capacity of the boiler which has efficiency of %80 is around 1.130.000 kJ/h and the fuel consumption is 12 tons per month. Almost %30 of the produced vapour is dismissed to atmosphere due to overdrive.

A new system is proposed to utilize this energy in dryer unit. Cylinders with the dimensions of drum are replaced with drum and pre-heater nozzles inside the finishing department. Drying process is accomplished by vapour passing inside cylinders located. Inside the finishing department, other equipment remains same situations. The new proposed system is given in figure 4.

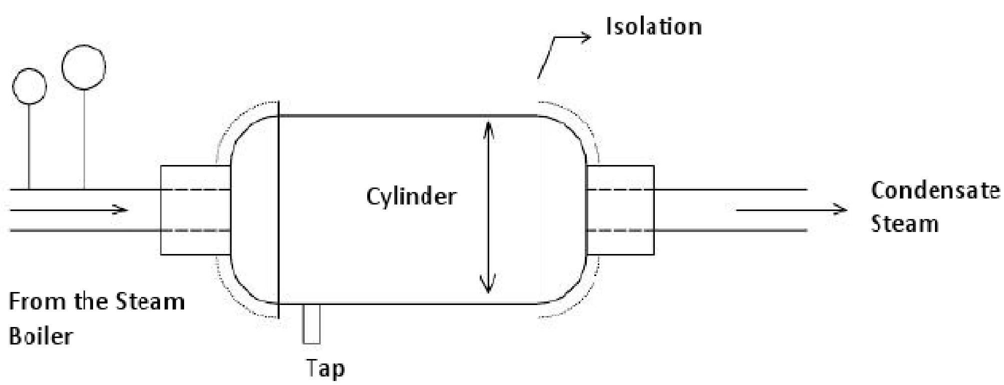

Figure 4. Proposed drying system

5.1. Energy consumption in the proposed system

Every day 150 carpets, each has 6 m^2 area, are dried by spreading diluted glue to the base of the carpets. Glue used for drying process is composed of homopolymer arid material with a ratio of %45 and %55 of water. 640 kg of water is added to 170 kg of homopolymer material and 810 kg of diluted glue is obtained and used on carpets daily. Total amount of water used for this process is determined around 61 kg/h and pure glue amount is around 6.5 kg/h. It is known that a 6 m^2 carpet is around 15 kg, so 187.5 kg of carpet can be dried hourly. Amount of water evaporated from carpet is calculated as 60 kg/h. Energy diagram for vapour dryer system is given in Figure 5.

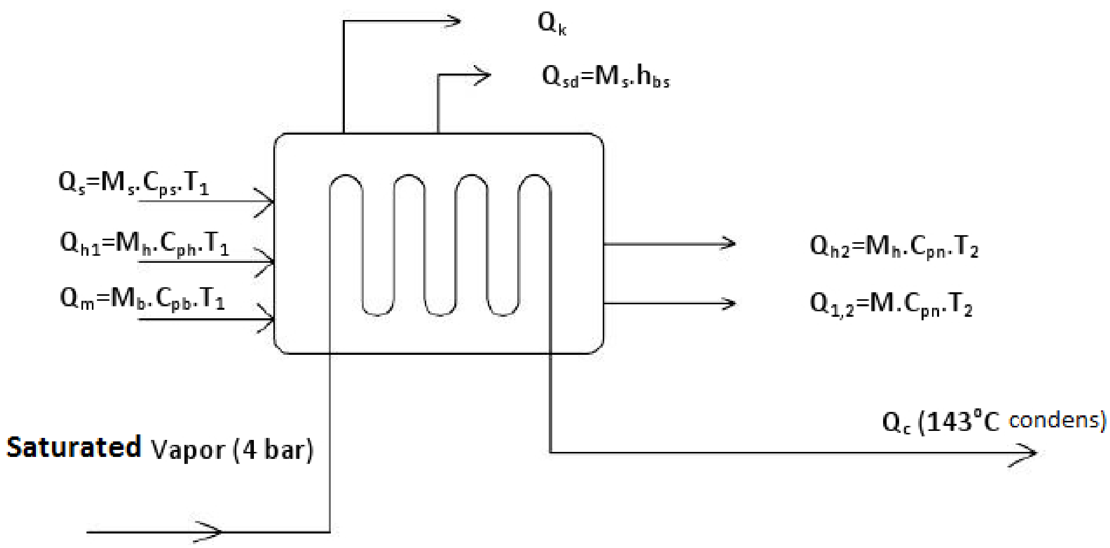

Figure 5. Energy Balance of steam

The energy given for carpet heating is [9];

$$Q_{(h_{12})} = Q_{(h_2)} - Q_{(h_1)} = m_{(h_a)} c_{p(h_a)} (T_2 - T_1) \tag{1}$$

Energy given for glue heating

$$Q_{(t_{12})} = Q_{(t_2)} - Q_{(t_1)} = mc_{p_1} (T_2 - T_1) \tag{2}$$

Energy given for heating the water to evaporate as be formulated as;

$$Q_s = m_s c_{p_s} (100 - T_1) \tag{3}$$

The energy required for evaporation of the water at 100 °C can be calculated from;

$$Q_{so} = m_s . h_b \tag{4}$$

Energy loss inside dryer system can be formulized as;

$$Q_k = k \left[Q_{(p_{12})} - Q_{(t_{12})} - Q_s - Q_{sb} \right] \tag{5}$$

Saturated vapour at 4 bar pressure and 143°C is applied to cylinder. Net energy given by saturated vapour can be characterized by the relations;

$$Q_b = m_b(h_b - h_c) = [Q(h_{12}) + Q(t_{12}) + Q_s + Q_{sb}] + k[Q(h_{12}) + Q(t_{12}) + Q_s + Q_{sb}] \tag{6}$$

Physical values of materials are listed in Table 1.

Table 1. Physical values of materials

Substance	Symbol *(i)*	Mass flow rate, *m* *[kg/h]*	Specific heat, Cp *[J/kgK]*
Carpet	H	187,5	1350
Glue	T	6,5	837
Water	S	61,0	4187

Furthermore some values are determined as;

Environment temperature T_i= 18 °C, outer surface temperature of heating cylinder T_2= 128 °C, inner surface temperature of the cylinder, T_3= 133 °C, heat of vaporization of the evaporating water at 1000 C (1 atm) hb= 2257 kJ/kg.

If the given values are plugged into the equations from (1) to (6), net energy required for vapour based dryer system can be roughly calculated as 243200 kJ/h.

The distance between vapour boiler and dryer unit determined around 80 meters.

Vapour can be delivered to dryer unit by pipes made of steal. Pipe dimension are decided such as piper diameter of 50 mm and thickness 2.7 mm. Pipe will be isolated by a glass wool of 50 mm thickness. It is assumed that, the temperature inside dryer drum is decreased towards 133 ^{0}C, when temperature inside vapour boiler is 143 ^{0}C. Heat loss inside pipe is shown in;

$$Q_{bk} = AUT_m - Q_{bk} \tag{7}$$

$$T_m = \frac{[(T_k - T_1) - (T_3 - T_1)]}{\ln\left[\frac{(T_k - T_1)}{(T_3 - T_1)}\right]} \tag{8}$$

$$AU = \frac{2\pi L}{\frac{1}{\alpha_1 R_1} + \frac{1}{\lambda_1} ln\frac{R_2}{R_1} + \frac{1}{\lambda_2} ln\frac{R_3}{R_4} + \frac{1}{\alpha_2 R_3}} \tag{9}$$

$$Q_{bkl} = kAUT_m \tag{10}$$

Where, L = 80 m, T_3=133°C, T_k=143°C, R_1 = 0.025 mm, T_1= 18°C, R_2= 0.0277 mm, R_3 = 0.0777 mm, λ_1 = 53.7 W/m.K, α_1 = 8000 W/m^2.K, λ_2 = 0.0398 W/m.K, α_2 = 24 W/m^2.K are taken in [9,10].

Energy loss of 15000 kJ/h is calculated, when given constants are inserted in equations (7) to (10). Total amount of energy required for new proposed vapour system can be given as;

$$Q_{net} = Q_b + Q_{bd} \tag{11}$$

When pre calculated values are plugged in equation 11, total energy of Q_{net}= 258200 kJ/h is found. Previous system has energy consumption of 310815 kJ/h by natural gas burn. Energy difference between proposed system and the natural gas system can be calculated by Q_{ng} - Q_{net} = 52615 kJ/h. A total energy saving of 52615 kJ/h is achieved through the new proposed system.

5.2. Heat amount absorbed from vapour boiler

A scotch type vapour boiler with the specifications of 4 bar pressure, 50 m surface and the efficiency η = %80 is available in the factory. B = 44.4 m^3 of natural gas with lower heating value of H_u = 34441 kJ/m^3 per hour is burnt in the boiler. In the blanket unit, almost k_l = %30 of the produced vapour is dismissed to the atmosphere. The energy dismissed to atmosphere from the boiler can be given as;

$$Q_{boiler} = B.H_u.\eta.k_1 \tag{12}$$

When the givens are placed in the equation, it is calculated that the energy value of Q_{boiler} = 367003 kj/h can be absorbed from the boiler. If the heat values of Q_{net} and Q_{boiler} are compared, it's seen that Q_{boiler} is higher than the Q_{net}; where $Q_{net} < Q_{boiler}$ (258200 < 367003). This proves that the energy obtained from the boiler can be used for carpet drying process in the finishing departments.

5.3. Advantages and Disadvantages for the proposed vapour dryer system

The proposed vapour system has many advantages over natural gas system. The initial manufacturing cost can be disadvantage for the proposed system but it can amortize itself and will be a profitable investment. The advantages of proposed system are;

- There won't be extra cost because of the vapour usage from blanket unit.
- The hazardous gas for workers will be removed from the environment.
- Reduced fire risk by the help of clean atmosphere air and the vapour.
- Autonomous control of the process.
- Minimized risk level of danger.
- Homogenized carpet base drying process by the vapour inside dryer cylinder.
- Heat loss can be prevented by the system isolation.
- The labour cost for system management will be reduced and this will lead the easiness of the system management.

5.4. Cost analysis for the proposed vapour system

613 kg of St 37-2 quality iron sheet is needed for dryer cylinder. 50 mm diameter of 170 meters pipe is required for vapour and **c**ondenses. 410 kg of glass wool for the isolation and 2 beds for the cylindrical dryer are utilized. Installation cost for the system is calculated as $3100 including equipment, labour and materials. The old system with natural gas costs $1295 per month so system will amortize itself within $3100/$1295 = 2.4 months. Annual profit of the factory will be $15540 because there will be no need for the natural gas procurement anymore.

6. Conclusion

Energy saving is achieved by the use of vapour system instead of natural gas burn in the finishing department in a carpet plant. Total income of $15540 will be attained by the removal of natural gas tubes from the system. A safe environment will be constituted for laborers health and security. It study can be a sample and applied to similar facility in Gaziantep region because %80 of the machine based carpet production is done in this region. This type of studies must become widespread among establishments which employ huge amount of energy and pile process churn.

References

[1] Haghi A. K. Thermal analysis of drying process a theoretical approach. The art of writing a scientific article. J of Thermal analysis and calorimetry, 2003;74:827–42.
[2] Francis N.D, Wepfer W.J. Jet impingement drying of a moist porous solid. Int. J. Heat Mass Transfer, 1996;39, 1911-23.
[3] Lee HK. Carr WW. Beckham HW. Leisen J. A model of through-air drying of tufted textile materials. Int. J. Heat Mass Transfer, 2002;45,357-66.
[4] Ogulata RT. Utilization of waste-heat recovery in textile drying. Applied Energy, 2004;79, 41–9.
[5] Cay A., Tarakcioglu I., Hepbasli A. Exergetic performance assessment of a stenter system in a textile finishing mill. Int. J. of Energy Research, 2007; 31:1251–65.
[6] Cay A., Tarakcioglu I., Hepbasli A. Assessment of finishing processes by exhaustion principle for textile fabrics: An exergetic approach. Applied Thermal Engineering, 2009;29, 2554–61.
[7] Dennis, LA. Buchanan, DR. Thermomechanical analysis of the stress history in heat set nylon 6 carpet yarns. Textile Research Journal, 1987; 57, 11, 625-39.
[8] Akyol U., Kahveci K., Cihan A. Determination of optimum operating conditions and simulation of drying in a textile drying process. J. The Textile Institute, 2013;104, 2, 170–7.
[9] Bejan A, Tsatsaronis G, Moran M. Thermal Design and Optimization. Wiley: New York.
[10 Bayazitoglu Y., Ozisik, N. A Textbook for Heat Transfer Fundamentals, Begell house Inc. Publishers, 2012.