Experimental Investigation of Heat transfer Characteristics and Heat Recovery Efficiency in Wire Rope Regenerator

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***Abstract*—This paper introduces experimentally the effect of wire rope diameter, porosity and regenerator material (copper and aluminum) on the pressure drop and friction factor. Comparison between wire rope pressure drop and wire mesh pressure drop was carried out which indicated that the pressure drop of wire rope is less than that of wire mesh. The conclusion is that the higher heat transfer can be achieved using regenerator with wire rope. The comparison among the results of the present work and those of the literature gave about 65% improvement in heat recovery efficiency (Regenerator effectiveness) rather than the wire mesh regenerator.**

Keywords: Heat transfer, wire rope, wire mesh, heat recovery, regenerator.

INTRODUCTION

The regenerator is type of heat exchangers and its main function is a heat recovery where it absorbs the heat from the working gas when the gas flows from the heater to the cooler and release heat during the reverse process. Many investigations have been performed to study the regenerator efficiency with various materials. The past researches used spring mesh, wire netting, stacked wire gauzes and sponge as regenerator. Makoto [1] showed the effect of wire diameter, regenerator length, working gas pressure on the regenerator performance with wire gauzes. It was found that the installation of wire gauzes with different wire diameters to the heater and cooler sides of the regenerator could improve the regenerator performance. Hamaguchi et al [2], investigated theoretically and experimentally the spring mesh as a new regenerator matrix. The results showed that the flow loss and heat transfer characteristics of spring mesh are slightly inferior to those of stacked wire gauzes. Geon, T and Byung, H, [3] carried out their experimental study to investigate the effects of the combination of regenerator materials on the regenerator efficiency in an oscillating flow. This study shows that the proper combination of regenerator constructions is important to enhance the regenerator efficiency. Tanaka et al [4] described the heat transfer characteristics of various types of regenerator materials (wire netting, sponge metal and sintered metal) under oscillating flow conditions. Lee et al [5] investigated the effects of the regenerator materials on the regenerator effectiveness in an oscillating flow. Ju, Jian and Zhou [6] designed a dynamic experimental apparatus to investigate oscillating flow characteristics in a regenerator.

The present work introduce a new design of regenerator in the form of wire rope, two materials were used in this work copper and aluminum respectively. Comparison between wire rope pressure drop and wire mesh pressure drop was carried out which indicated that the pressure drop of wire rope is less than that of wire mesh. The friction factor and Reynolds number was calculated. Also, the present study introduces an experimental investigation in improvement of the heat recovery efficiency with the wire mesh regenerator.

EXPERIMENTAL TEST RIG

The test rig was constructed to determine the heat transfer characteristics and pressure drop from the regenerator with wire rope and wire mesh respectively. The test rig was fabricated and assembled as shown in figures (3-5). The flowing table (1) shows the components of the test rig.

A definite number of pre-calibrated *K*-type thermocouples of 0.3 *mm* wire diameter, of 1mm probe diameter and of 20 *ms* response time, [7,8] were used to measure the coolant inlet and outlet temperatures. The thermocouples were connected to a data acquisition system through two multiplexers (multiplexer 4051) via buffers and amplifiers. A Q Basic language software program was prepared to control the data collection and *monitoring*. This package gives a resolution of $0.01\,^{o}C$ for temperature measurement. Suitable interface hardware circuits are constructed to connect between the personal computer and measuring equipments.

A PC-based data acquisition system utilizing PLC-818PG and a data logger was used for data collection and monitoring**.**

The specimens used in this work were the wire mesh (fig.1) and wire rope respectively. Wire rope is a type of cable which consists of several strands of wire laid (twisted) into a helix. The wire rope as shown fig.(2) was easy to prepare, easy control of the porosity and good handling.

Data Reduction Equations

The data reduction of the measured results is summarized in the following procedures:

The air flow rate was calculated from formula [ ],

$M_a = C_d.E.e.d^2{}_o \sqrt{2.\rho f.g.\Delta H}\rho_a$ (1)

The rate of heat transfer Qrej from the air is:

$Qrej = m_a\, Cp_a\, (T_{air,in}-T_{air,out})$ (2)

The rate of heat transfer was added to the water is:

$Q_{add} = m_w\, Cp_w\, (T_{w,,out}-T_{w,in})$ (3)

The rate of convective heat transfer is:

Q = A h ∆T. (4)

Regenerator effectiveness is;

$$\dot{\eta} = \frac{Qh,in - Qc,out}{Qh,in - Qc\,,in} \quad (5)$$

where:

Qh,in =input heat from heater

QC,out =output heat to cooler

Qc,in =input heat from cooler

The Reynolds number on the air side is defined as:

$$\mathrm{Re} = \frac{u_{\max} D_h}{\nu} \quad (6)$$

D_h = the hydraulic diameter of the heat exchanger:

The Nusselt number is defined as:

$$Nu = \frac{h_o\, D_h}{k} \quad (7)$$

The friction factor is defined according to [9] as:

$$f = \frac{A_{ff}\,\rho_m}{A_o\,\rho_i}\left[\frac{2\Delta P\,\rho_i}{G^2} - \left(1 + \sigma^2\right)\left(\frac{\rho_i}{\rho_o} - 1\right)\right] \quad (8)$$

Where:

$$u_{\max} = \frac{u}{\sigma}\ ,\quad \rho_m = \frac{\rho_i + \rho_o}{2}\ ,\quad \sigma = A_{ff} / A_{fr}\ ,$$

$$G = \frac{\rho\, u}{\sigma}$$

Porosity is defined according to as:

Y = Vair /(Vair + Vsoild) (9)

RESULTS AND DISCUSSION

Figure (6) indicates the comparison between the pressure drop of wire rope and wire mesh specimen. The figure indicates that the pressure drop in wire rope specimen is smaller than the pressure drop of wire mesh for the same flow rate although the porosity of wire mesh is greater than that of wire rope.

Figure (7) indicated the pressure drop of copper specimen is higher than that of Aluminum specimen at high flow rate. But at low flow rate the pressure drop of aluminum specimen is higher than that of copper as shown in the figure

The reason of this difference in the pressure drop is due to the surface roughness of copper specimen which is not the same as that of aluminum specimen.

It is obvious from figure (8) that the friction factor increases as the porosity increases. The figure also indicates the friction factor decreases with increase in Reynolds number.

Figure (9) indicates the variation of Nusselt number with Reynolds number of the regenerator with wire mesh and wire rope restrictively. The Nusselt number for wire rope is higher than the regenerator with wire mesh. The results obtained led to the conclusion that the higher heat transfer can be achieved using regenerator with wire rope.

Figure (10) indicates about 65% improvement in heat recovery efficiency (Regenerator effectiveness) rather than the wire mesh regenerator.

CONCLUSION

The conclusions of this work can be assembled as the following items:

1- Regenerator effectiveness depends on the following:

a- Porosity of the regenerator material.

b- The pressure drop in the regenerator.

c- Type of the regenerator material and its dimensions.

d- Design and effectiveness of each cooler and heater.

e- Rate of the air flow.

2- The pressure drop of wire rope specimen is less than the pressure drop of wire mesh specimen.

3- The porosity of wire rope specimen is less than that of wire mesh specimen because the flow inside the wire rope specimen is straight but the flow inside the wire mesh specimen is not straight.

4- The friction factor of wire rope specimen is nearly the same at high air flow rate. The friction factor increases as the porosity increases. The flow loss of wire rope regenerator is less than that of wire mesh regenerator.

5- About 65% improvement in heat recovery efficiency rather than the wire mesh regenerator.

Nomenclature

A	heat transfer surface area, m^2
C_p	specific heat, J/kg.K
C_d	Coefficient of discharge
D_h	hydraulic diameter, m
E	Velocity of approach factor = $(1-\beta4)^{-1/2}$
h	heat transfer coefficient, $W/m^2.K$
k	conduction heat transfer coefficient, W/m.K
m	mass flow rate, kg/s,
Nu	average Nusselt number, ($h\ .\ D_h/k$)
Q	heat transfer rate, W
Re	Reynolds number
U	air velocity m/s
V_c	minimum free flow volume, m^3
ρ	density, kg/m^3
μ	dynamic viscosity, N.s/ m^2

Subscripts

i	inlet
a	air
o	outlet
w	Water
av	average
f	fin
h	hydraulic

Figure (1) Wire mesh

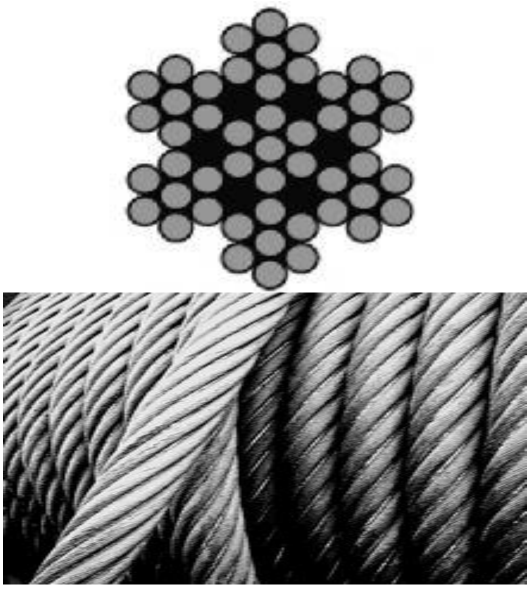


Figure (2) Wire rope

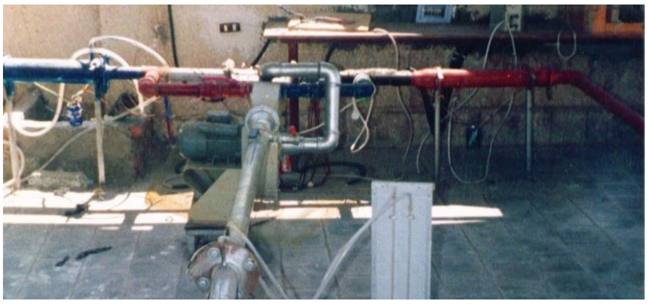


Figure (3) photograph of the experimental test rig and measuring equipments.

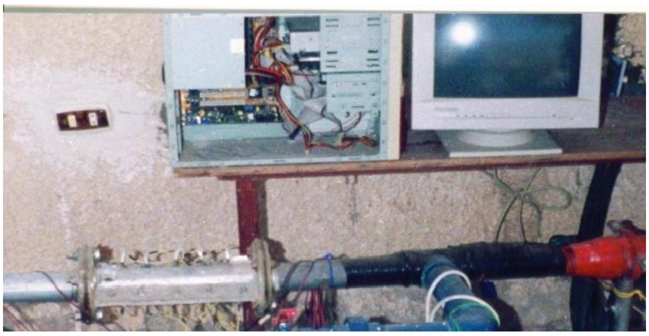


Figure (4) photograph of the experimental test rig with PC computer and data acquisition card.

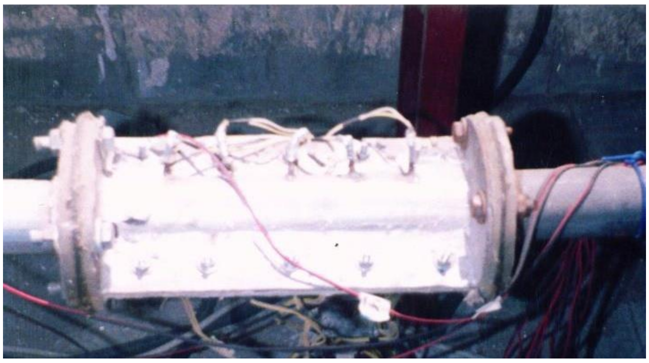
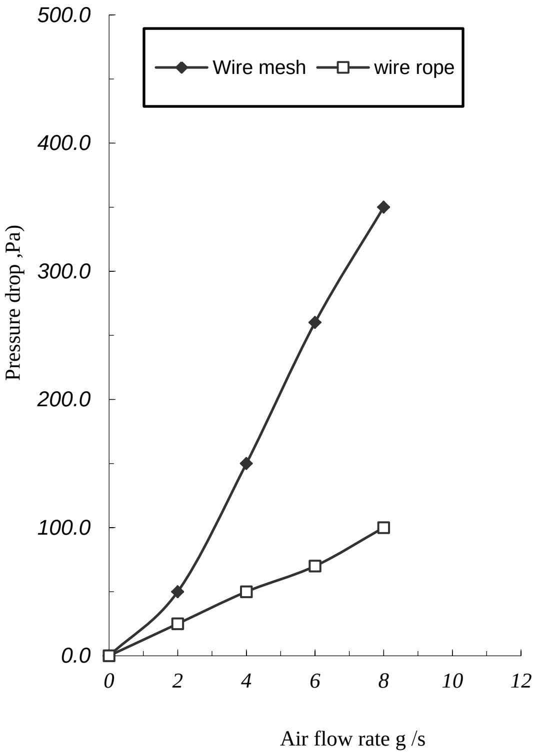


Figure (5) photograph of the regenerator



Figure(6) Comparison between pressure drop of wire rope and wire mesh

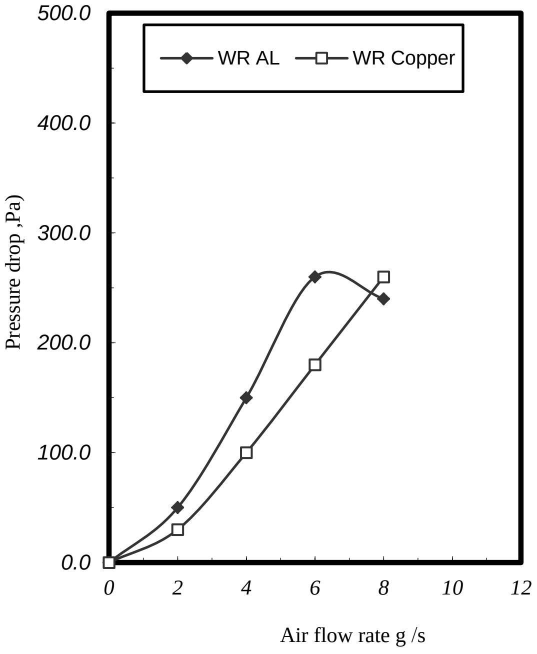


Figure (7) Effect of wire material on the pressure drop at **Ŷ** =0.431

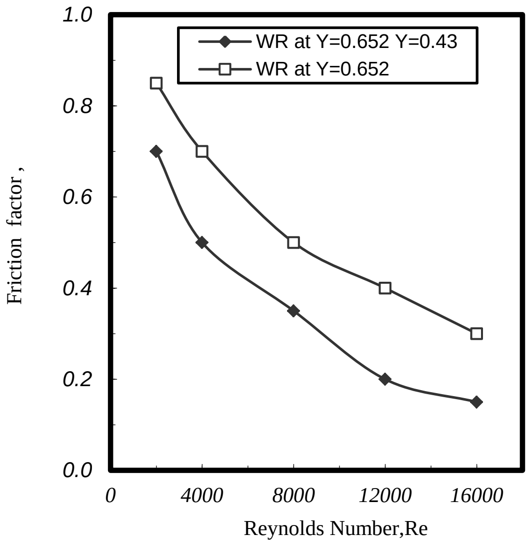
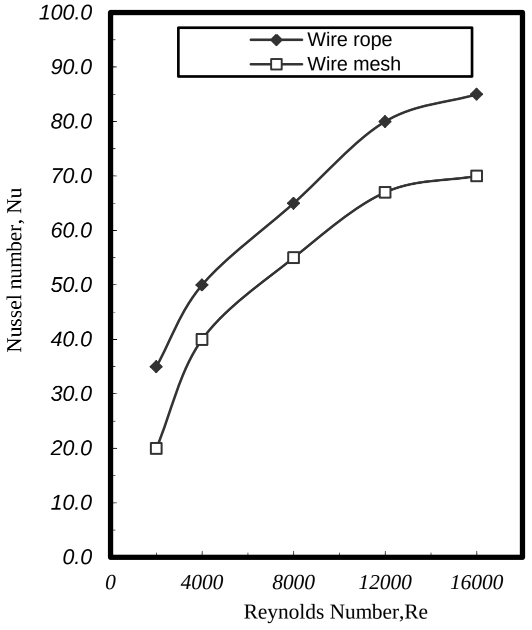
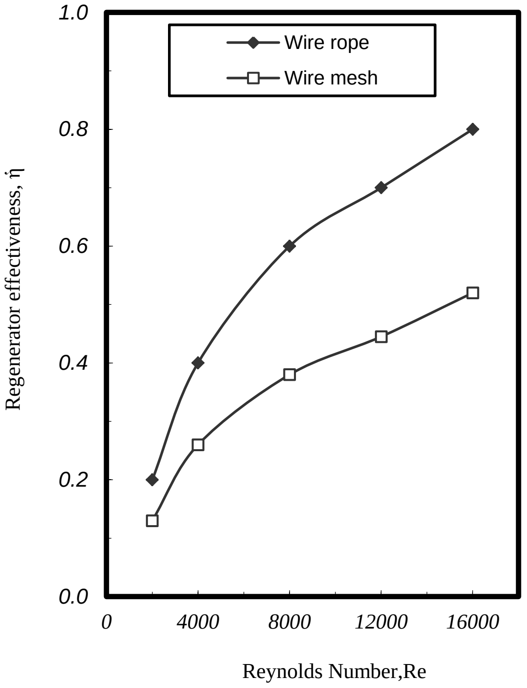


Figure (8) Effect of porosity on the friction factor for the same wire diameter (d=1.7 mm)



Figure(9) variation of Nusselt number with Reynolds number of the regenerator with wire mesh and wire rope



Figure(10) Comparison of Regenerator effectiveness with wire mesh and wire rope

Table (1) shows the components of the test rig.

1	Blower , 2.5hp	9	Thermocouples
2	Heater	10	Autotransformer
3	Regenerator	11	PC computer
4	Cooler	12	Data acquisition card
5	Air duct	13	U- manometer
6	Control valves	14	Electronic control circuits
7	The specimens	15	Control Panel
8	Orifice plate meter		

References

1- Makoto Tanaka," Effect of Wire diameter on regenerator performance" , Mechanical engineering lab., Agency of industrial science and technology, MITI, Japan,1993.

2- Kazuhiro Hamaguchi, "Spring mesh regenerator", Hokkaido polytechnic college, Otaru, 47-02 Japan, 1997 .

3-Geon Tae Lee and Byung Ha Kang, " Improving regenerator efficiency" , Air conditioning and Environmental control lab. , Korea institute of science and technology ,Seoul, Korea, 1997. . 4- Makoto Tanaka, Iwao Yamashita and Fumitake Chisaka," Flow and heat transfer characteristics of the stirling engine regenerator in an oscillating flow", JSME international Journal ,Vol.33, No.2 ,1990. 5- Geon Tae Lee, Byung Ha Kang and Jae Heon Lee, "Effectiveness enhancement of a thermal regenerator in an oscillating flow", Applied thermal engineering , Vol.18, No.8, pp.653-660, 1998.

6- Tonglin Ju, Yan Tiong and Yuan Zhou, "Experimental study of the oscillating flow characteristics for a regenerator in a pulse tube cryocooler ", Cryogenics 1998, Volume 38, No.6.

7. J.P. Holman, Experimental Methods for Engineers, McGraw-Hill International Edition, Seventh Edition, New York, USA, 2001.

8. J.P. Holman, Heat transfer, McGraw-Hill International Edition, Ninth Edition, New York, USA, 2002.