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DESIGN OPTIMIZATION OF RECUPERATOR FOR MICROTURBINE

Yastuti Rao Gautam[1] ,Ajeet Pratap Singh[2], Shishupal Singh[3]

1, 2, 3, Mechanical Engineering Department, UIET CSJMU Kanpur

raoyastuti15 @gmail.com

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ABSTRACT

Recuperates are fundamental to accomplish the efficiencies wanted for progressed microturbines. It is troublesome to accomplish warm effectiveness bigger than 20% without utilizing of recuperate. In this manner in arrange to accomplish effectiveness of 30% and higher, a recuperate gets to be imperative for microturbines. In the show work curved corrugation thwarts sort essential surface recuperate (PSR) considered. Warm exchange coefficient, weight misfortune and weight of PSR factors are optimized by hereditary calculation.

Keywords: Recuperator, microturbine, genetic algorithm, elliptical corrugation foil, PSR

1. INTRODUCTION

Microturbines are combustion turbines with control yields roughly in the extend of 25–300 kW. In these small scale turbine by Liu Zhenyu, 2007 common gas is utilized as fuel for tall execution . In any case, productivity as it were up to 20% can be accomplished with the microturbines and expansive sum of warm is depleted.

This warm can be utilized with the offer assistance of recover to accomplish the warm effectiveness up to 30% or same times indeed higher warm proficiency is conceivable to accomplished by C.F. McDonald,1996. Cui Rongfan et al., 2003 have portrayed the beginning age of recuperator was bulky estimate, destitute auxiliary and tall fetched of recuperator. For long time, numerous specialists have been making extraordinary work to resolve the obstructions. Alberto Traverso et al., 2005 displayed a unused approach for the optimization of microturbine recuperators from the specialized and financial points of view. The strategy proposed has been executed in the program called CHEOPE (compact warm exchanger optimization and execution assessment). A few creators work done by limited component strategy utilizing the overseeing conditions are the incompressible Navier-Feeds, coherence and vitality conditions by Kenichi mortimoto et. al., 2005. Cai Ruixian et al., 2005 have portrayed the warm proficiency recuperative gas turbine cycle with a recuperator found between a high-pressure turbine and a low-pressure turbine (elective recuperative cycle, Bend) is analyzed and compared with the basic cycle and customary recuperative cycle (CRC) . An investigation program to reenact the operation of a microturbine CHP framework was set up and approved by utilizing measured test information. The infusion of hot water, which is created at the warm recuperation unit, at two diverse areas interior the microturbine was anticipated Combined warm and control by Jong Jun Lee et al., 2009. In the essential vitality comprised for the most part mineral powers are utilized, which have restricted saves and whose utilization may cause genuine natural impacts. Consideration has been paid to found clean and renewable assets such as syngas by Luciana M. Oliveira Marco et al., 2009.So that crucial necessity for recuperator is compact measure, great warm proficiency and moo fetched, specifically essential surface recuperator. The essential surface recuperator (PSR) is a new recuperator concept for microturbines.

According to the M.R. Jafari Nasr, 2000 the requirements for good recuperator are

(1) High heat transfer coefficient and low pressure loss. These affect the gas turbine cycle efficiency.

(2) High reliability and durability for low maintenance cost for long life time.

(3) The weight is directly proportional to material cost . So as the weight reduces manufacturing coast reduces. Small volume of the micro turbine unites easier to handle. Also efforts have been mate by considering heat transfer coefficient, pressure loss and weight of recuperators.

However, only one or two variables were considered by authors .These variables optimize by traditional methods which are having certain limitation. If traditional methods get first maximum or minimum value the will stop, not search next minimum or maximum value in the whole giving regions. In the present work optimization method proposed by using genetic algorithm considering all three variables: heat transfer coefficient, pressure loss and weight of recuperator, application of genetic algorithm (GA) remove limitation of traditional methods.GA search maximum or minimum value in whole region. Also generate parameters of an elliptical corrugated foil recuperator are also considered for optimization by Liu Zhenyu, 2006. As it is strongly effects the heat transfer rate and flow resistance of recuperator core.

2. STRUCTURE DESCRIPTION AND HEAT TRANSFER CONCEPT OF PSR

E. Utriainen, 2002 have described the PSR is mainly made of core, exhaust ducts and structure supporting assembly. The core is the main heat transfer part. It is the core that the whole recuperator depends on to realize the heat exchange between the flue gasses of high temperature but low pressure from turbine and the air of low temperature but high pressure from compressor. The piled foils have lots of small channels with hydraulic diameters around 1 mm and thickness of foil around 0.1mm.Hot gasses and cold air flow through the solid corrugated foil in the counter flow direction. Hot gases are flue gasses coming from micro turbine and the cold air comes from the compressor. Straight flow channels are used in order to make good use of the high heat exchange performance and to utilize most front face area so as to reduce the flow resistance pressure. The basic parameters of corrugation curve involve two short semi axes of the adjacent curves a_1, a_2 and long semi-axis b by Liu Zhenyu, 2006 (Fig.1).

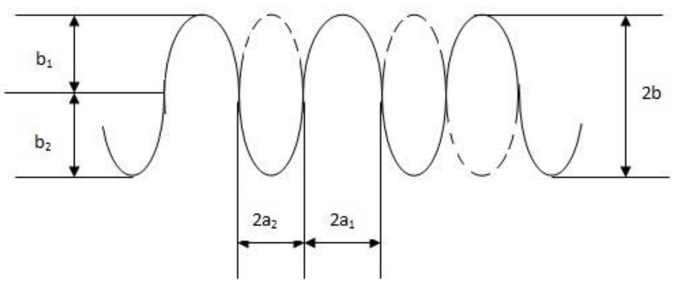


Fig.1 Geometry of corrugated foil of primary surface recuperator

The flow passages of flue gas and air inside the PSR recuperative core are shown by E.L. Parsons, 1985 in Fig. 2. The airflow passage in shape of letter ‘Z’, while the flue gasses flow passage is of linear shape. The enter zone and exit zone of ‘Z’ shape passage are defined as ‘diversion zone’, which contributes to distribute or collect the air when it enter or exit the PSR core. The air and flue gas are in cross flow in the diversion zone. The middle zone of ‘Z’ shape passage, ‘main flow zone’, which is the primary zone for the cold air and hot gas to exchange heat. This zone cold air and hot gas are in counter flow.

3. MICROTURBINE UNIT

Micro and mini gas turbines are used in power generation technology. They play an important role in power generation both for standalone and for combined cycle application with fuel cells. The micro- turbine

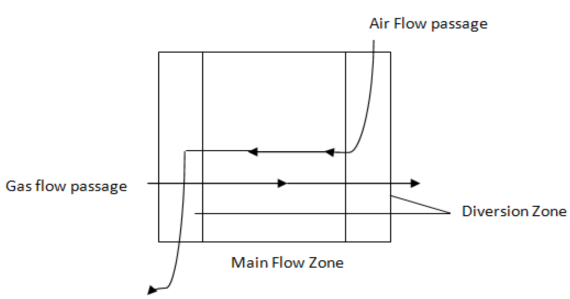


Fig.2 Flow passages of air and flue gas in primary surface recuperator core unit consists of a compressor and a turbine connected on a single shaft. Moreover there are a combustion chamber and a recuperator (Fig.3).

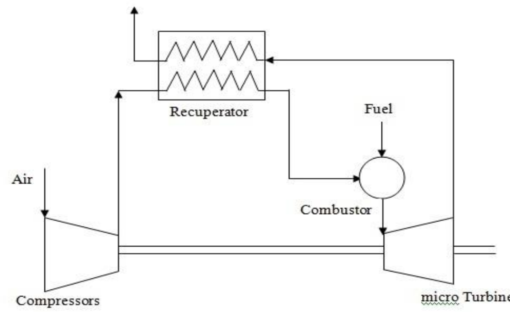


Fig. (3) Microturbine unit

4. CONSTRUCTION DETAILS OF RECUPERATOR

E. Utriainen, et al., 2002 have described the primary surface annular counter-flow direction in recuperator is considered for design the recuperator geometry is formed by a single spool of thin foil which is stamped and folded to make passages for air and gas flow and this folded geometry is press fitted between two hollow cylinders and welded to the ends of the air passages at both ends and closed and welded by flanges. Flue gasses enters the recuperator at one end and flows axially along the length of the recuperator whereas air enters the recuperator from opposite end radially through elliptical holes formed at both ends of the recuperator radially, takes a longitudinal path along the length of recuperator and comes out of it again through an elliptical passage.

5. OPERATING PARAMETERS OF PRIMARY SURFACE RECUPERATOR

There is different type of curve shape these are elliptical, sinusoidal, parabolic and rectangular. According to H.E. Cheng et al. 2000, elliptical corrugation gives the best performance in terms Reynolds no., heat transfer coefficients, pressures loss and compactness etc. So in the present work corrugation of elliptical shape are considered for microturbine for 100kW, in Table (1) by Liu Zhenyu ,et at., 2006.

Table (1)

parameters	Gas side	Air side
Working substance	Flue gas	Air
Mass flow rate	1.03 (Kg/s)	1.0(Kg/s)
Inlet temperature	660 (°C)	184 (°C)
Outlet temperature	282	612
Inlet pressure	109.92 (kPa)	381.12 (kPa)
Allowable pressure drop	0.06 (%)	0.035 (%)

Geometrical parameters presented in Table (2)

Table (2)

Geometry Parameters	Dimensions
$2a_1$	0.6 mm
$2a_2$	0.8 mm
2b	1.3 mm
δ	0.1 mm
w_b	5mm
δ_d	1.5mm

6. MATERIAL FOR RECUPERATOR

J. M. Rakowski, 2005 have described the primary surface recuperator operates at high temperatures and gasses pressures and recuperator is constructed from thin metal sheet sections. Such a primary surface recuperator design presents several. unique challenges for high-temperature materials.

Water vapour present in the exhaust gas as a by-product of combustion, has been shown to be detrimental to the elevated temperature oxidation resistance of common in stainless steels. So that increases the amount of chromium required to form a protective oxide film. The exhaust gas temperature of micro turbine unit is aground 1000 to 1400 °C so that stainless steel is suitable material for recuperator which can wear this temperature and the thermal conductivity is very high. 304 alloy steel material is selected for recuperator by J. Kesseli, 2003.

7. FUEL USED IN MICRO GAS TURBINE

There are various types of fuels like liquid (fuel oil), solid(coal) and gaseous fuels are available for firing in boilers, furnaces and other combustion equipments. The selection of right type of fuel depends on various factors such as availability, storage, handling, pollution and cost of fuel. Natural gas is the most s suitable fuel for micro gas turbine as very low pollution and also have low cost etc. Natural gas is one of the major combustion fuels used throughout the country. It is mainly used to generate industrial and utility electric power, produce industrial process steam and heat, and heat residential and commercial space according to the 10 KW MICRO GAS TURBINE, 2006.

Methane is the main constituent of Natural gas and accounting for about 95% of the total volume. Other components are: Ethane, Propane, Butane, Pentane, Nitrogen, Carbon Dioxide, and traces of other gases. Very small amounts of sulphur compounds are also present. Since methane is the largest component of natural gas, generally properties of methane are used when comparing the properties of natural gas to other fuels.

8. DESIGN OPTIMIZATION OF RECUPERATOR:

The steps in the design require the determination of the following factors by D. G. Wilson, 2003:

1. Nusselt no. and Prandtl Number
2. Reynolds number.
3. Overall coefficient of heat transfer
4. Pressure drop
6. Weight of PSR

8.1 Nusselt Number according to Liu Zhenyu et. al. 2006

$$Nu = 0.031Re^{1.18}Pr^{0.4}(h/W_c)^{0.19} \quad (1)$$

where h and W_c are height and width of the small rectangular channel.
However can be used for elliptical corrugation by M.D. Xin, el al.,1995, also by replacing the height (long side) 4b and width (short side) 2a of PSR channel are put in place of h and W_c, respectively.

$$f = \frac{112}{Re} \tag{2}$$

The applicability of Eq. (2) is Re < 1000.

8.2 Over all heat transfer convection coefficient
[Liu Zhenyu et al., 2006**]**

The heat-conducting resistance of corrugated foil is not needed be considered because of its thickness is only 0.1 mm.

$$\frac{1}{U} = \frac{1}{h_1} + \frac{1}{h_2} = \frac{d_{e1}}{Nu_1 k_1} + \frac{d_{e2}}{Nu_2 k_2} \tag{3}$$

According to the law of heat convection in PSR channels and the geometric of these channels, the equation is simplified as follows:

$$\frac{1}{U} = \frac{\nu_1^{1.18}}{0.0031 Pr_1^{0.4} k_1} \left(\frac{a_1}{2b}\right)^{0.19} \frac{1}{u_1^{1.18} de_{e1}^{1.1}} + \frac{\nu_2^{1.18}}{0.0031 Pr_2^{0.4} k_2} \left(\frac{a_2}{2b}\right)^{0.19} \frac{1}{u_2^{1.18} de_{e2}^{1.1}} \tag{4}$$

8.3 Pressure loss:

According to the flow of flue gas in PSR core, it is known that the general pressure drop Δp_2 is made up of inlet pressure drop Δp_{i2}, outlet pressure drops Δp_{e2} and pressure drop in main flow zone Δp_{n2}.

$$\Delta p_2 = \Delta p_{n2} + \Delta p_{i2} - \Delta p_{e2} \tag{5}$$

The four parameters a_1, a_2, b and u_1 on Δp_{i2} and Δp_{e2} are very small and Δp_{i2} and Δp_{e2} are both much lower than Δp_{n2}, therefore, the pressure loss of flue gas Δp_2 in Eq.(5) can be simplified by Liu Zhenyu et al. 2006.

$$\Delta p_2 \cong \Delta p_{n2}$$

$$\Delta p_2 \cong 56 \rho_2 u_2 \nu_2 \cdot \frac{L}{d_{e2}^2} \tag{6}$$

8.3 Weight of Primary Surface Recuperator

The structural mass of PSR core has three parts: the mass of foils, the mass of side stripes and the mass of upper and nether end plates. According to the geometric features of PSR, the calculating equation is deduced as

$$W_r = \left[n\delta \frac{Pw}{4(a_1+a_2)} + 2n\delta_b w_b + 2\delta_d W_z \right] L_z \rho_z \tag{7}$$

there are curtain constraint are applied over here . These constraint given by Equation (7)-(19).

$$c_1 \le a_1 \ge c_2 \tag{8}$$

$$c_3 \le a_2 \ge c_4 \tag{9}$$

$$c_5 \le b \ge c_6 \tag{10}$$

$$a_1 - a_2 \le c_7 \tag{11}$$

$$c_8 \le u_1 \ge c_9 \tag{12}$$

The ninth constraint is size relationship between cold and hot channels:
The tenth to thirteenth constraints are the bounds of pressure drop limitation of cold and hot mediums:

$$c_{10} \le 56 \rho_1 u_1 \nu_1 \frac{L}{d_{e1}^2} \cdot \frac{1}{p_1} \le c_{11} \tag{13}$$

$$c_{12} \le 56 u_2 \nu_2 \frac{L}{d_{e2}^2} \cdot \frac{1}{p_2} \le c_{13} \tag{14}$$

The fourteenth to nineteenth constraints are the equality relationship of dependent variables with respect to independent variables:

$$m_2 \rho_1 a_1 u_1 - m_1 \rho_2 a_2 u_2 = 0 \tag{15}$$

$$P - 2(a_1 + a_2) - 8b = 0 \tag{16}$$

$$d_{e1} - \frac{16 a_1 b}{a_1 + a_2 + 4b} = 0 \tag{17}$$

$$d_{e2} - \frac{16 a_2 b}{a_1 + a_2 + 4b} = 0 \tag{18}$$

$$L - \frac{Q}{k \Delta t_m} \cdot \frac{8(a_1+a_2)b}{P} \cdot \frac{\rho_1 \rho_2 u_1 u_2}{m_2 \rho_1 u_1 - m_1 \rho_2 u_2} = 0 \tag{19}$$

$$n - \frac{Q}{k\Delta t_m} \cdot \frac{4(a_1+a_2)b}{P \cdot w \cdot L} = 0 \quad (20)$$

Equation (7) to (10) shows the constraint for size equation (11)-(13) represent the constraint for the pressure drop for cold side and hot fluid ,Equation (14)-(19) represent relation between dependent and independent variable. In Equation (14)-(19) independent variables are a_1,a_2 and b other variables are dependent variables ρ_1 and ρ_2 are the densities of hot and cold fluid which constrained by pressure and temperatures of the respective fluid. $c_1 - c_6$ determinant in the response to probable range of PSR chainels.c_7-c_8 response Reynolds numbers .c_9-c_{13} desired requirement of pressures loss.

9. OPTIMIZATION PROCEDURE

When the recuperator design is optimized for a particular application, different targets can be pursued as properties, such as the high heat-transfer performance, the light weight and the low pressure loss. These variables are optimized by genetic algorithm and the optimization equations are

$$maxf(x) = max\ (\mathrm{U(x)}) = max\left(\frac{1}{.00789\left(\frac{a_1}{2b}\right)^{0.19} + .002669\left(\frac{a_2}{2b}\right)^{0.19}}\right) \quad (21)$$

$$minf(x) = min(\Delta \mathrm{p(x)}) = min.\left(5.45\,\frac{(a_1)^2+(2b)^2}{{a_2}^2 b^2}\right) \quad (22)$$

$$minf(x) = min(W_r(\mathrm{x})) = \min\left(\frac{1.32}{(a_1+a_2)} + 27.74\right) \quad (23)$$

10. RESULT AND DISCUSSION

The optimized results are getting by genetic algorithm. Optimization design of the PSR based on its operating parameters and design requirements presented in Table 1. The material of foils is no. 304 stainless steel and the thickness of foils is 0.1 mm. It is required that the designed PSR should be high heat-transfer coefficient, low pressure loss and light weight simultaneously as possible under the specified conditions. The result calculated by routine method is presented as a comparison and the optimization design results. The results show that it is effective to use a genetic algorithm technique to search and combine optimal parameters for recuperator under different requirements- heat transfer coefficient, pressure drop and weight. Making use of a genetic algorithm provides strong ability of search and optimization, which effectively might be better than the traditional method, since there is always the possibility that the results from GA the better optimal

By the optimization method the maximum value of heat transfer coefficient is, The optimized value of pressure loss 92.9 Pa and the weight of recuperator is 29.6 kg. by the routine method the value U, Δp_2 and W_r are 130 W/m^2 °C, 104.142 Pa and 30.4 Kg respectively in the Fig.(4) is shown that the min. value of 1/U is 6.3×10^{-3} so that the maximum value of heat transfer 158 W/m °C is done by 250 generation (no. of iteration) ,by GA . in the Fig.(5) shows that the minimum value of pressure loss is 92.9 Pa by 100 generation and Fig.(6) shows the minimum value of weight of 29.6 kg by 100 generation.

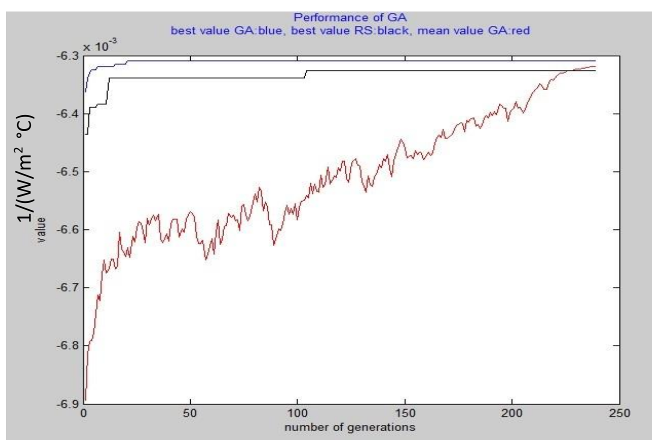


Fig.4 total heat transfer coefficient graph by GA

The Fig. (7) and (8) shows that total heat transfer coefficient are decrease with increases the value of a_1

and a_2 because U is inversely proportional to a_1 and a_2 and total heat transfer value increases with b in Fig. (9) , U is directly proportional to b by the formula. The Fig. (10) is shows that the total pressure loss in air side is decreases with respect to increases the value of a_1 and in Fig. (11) the pressure loss is increases with respect to increase a_2 and in Fig. (12) the pressure loss decrease because the pressure loss is inversely proportional to a_1 and b.

The Fig. (13) is shows that the total pressure loss in hot gas side is decreases with respect to increases the value of a1 and in Fig.(14) and (15) the pressure loss is decreases with respect to increase a_2 and b because the pressure loss is inversely proportional to a_2 and b. from the Fig. (16) and (17) are show that there are not more variation in weight of recuperator with respect to change there geometry parameters.

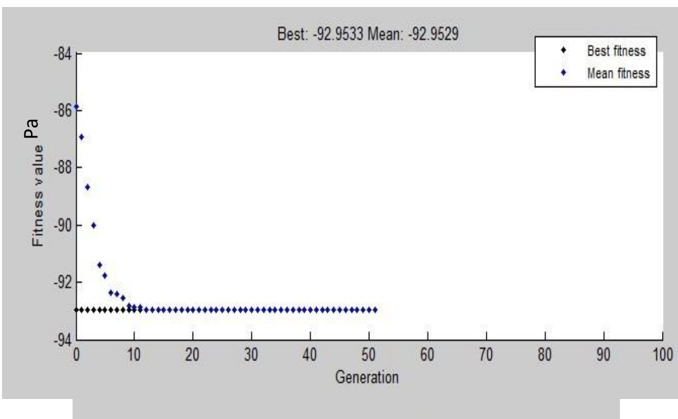


Fig.(5) total pressure loss in hot gas side by GA

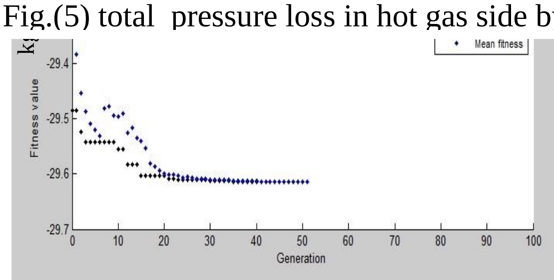


Fig.(6) weight of recuperator By GA

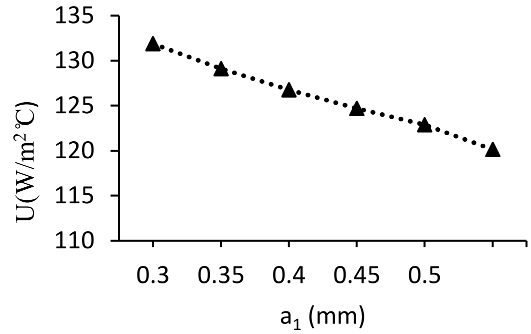


Fig. (7) total heat transfer coefficient Vs a_1

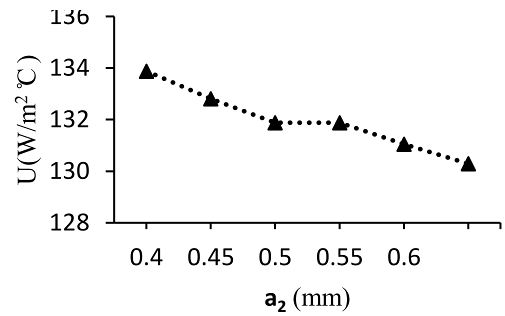


Fig. (8) total heat transfer coefficient Vs a_2

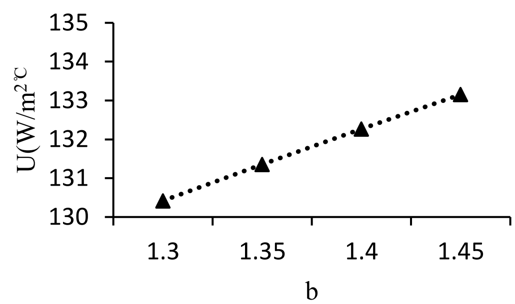


Fig. (9) total heat transfer coefficient Vs b

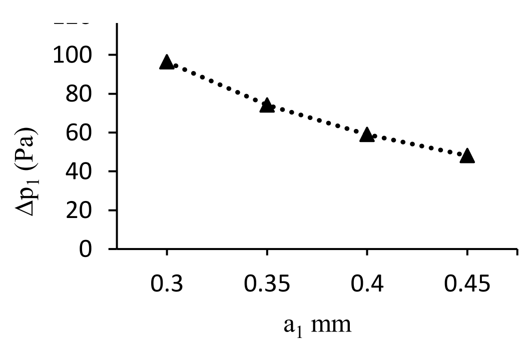


Fig. (10) total pressure loss in air side Vs a_1

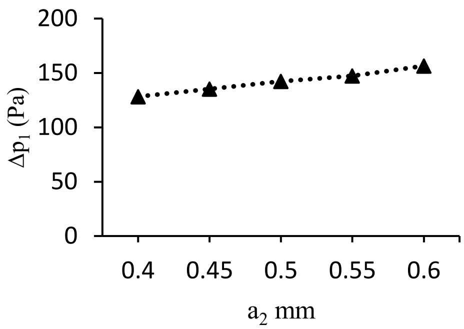


Fig. (11) total pressure loss in air side Vs a_2

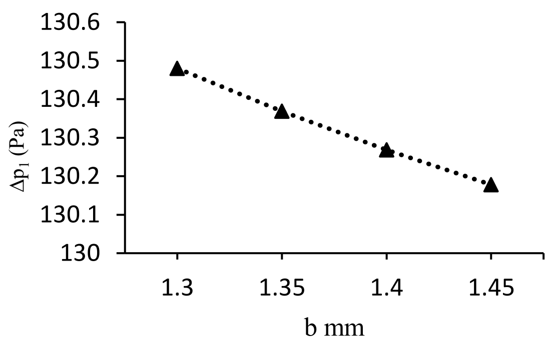


Fig.(12)total pressure loss in air side Vs b

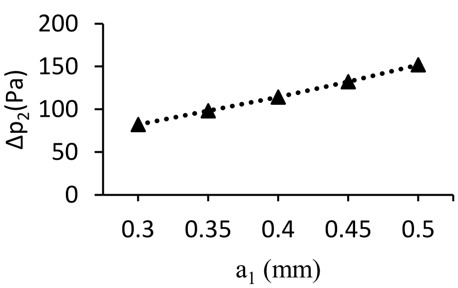


Fig. (13) total pressure loss in hot gas side is Vs a_1

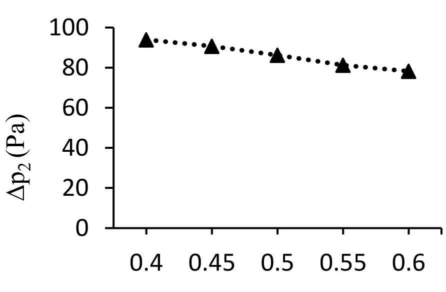


Fig.(14) total pressure loss in hot gas side is Vs a_2

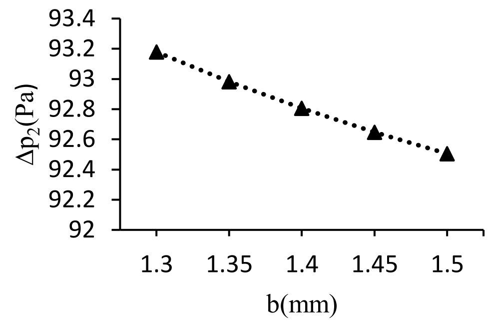


Fig. (15) total pressure loss in hot gas side is Vs b

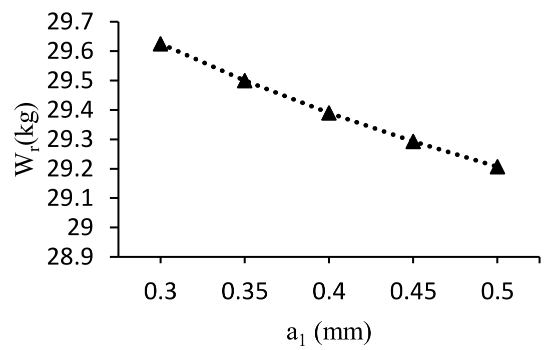
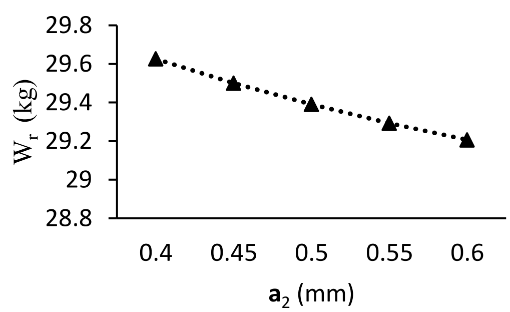


Fig. (16) Wt. of PSR Vs a_1



11. CONCLUSION

The plan of a recuperator for a 100kW small scale gas turbine has been carried out for given working conditions.

Concurring to the auxiliary characteristics and warm exchange hypothesis of essential surface recuperator, GA is a utilized for optimized recuperator. The comes about gotten from the optimization are, add up to weight drop in hot stream passes was close approximately 0.09% close almost admissible constrain, the extent of weight misfortune is 100 to 90 Dad in diminishing arrange with regard to expanding the esteem of a2 and b , but the weight misfortune is 80 to 160 Dad with regard the expanding esteem of a1 and add up to weight misfortune in cold stream passes in the run of 114 to 48 Dad in diminishing arrange with regard to a1 expanding and weight misfortune in expanding way extend 96 Dad to 156 Dad , but there are no impact on weight misfortune the expanding the esteem of b, warm exchanges coefficient is exceptionally tall but diminishes with expanding the esteem of a1 and a2 ,in the run of 134 to 80 W/m2 °C, and too the weight of recuperator is light. Warm exchange coefficient fundamentally depends on the geometry of essential surface recuperator. It is concluded that the hereditary calculation can give a solid capacity of optimization plan of recuperator compared to the conventional plans in which a trial-and mistake prepare may be included. By application of the hereditary calculation in the ideal plan the recuperator geometry or parameters can be optimized .

NOMENCLATURE

a	half width of corrugation, mm
b	half length of corrugation, mm
de	hydraulic diameter, mm
f	resistance coefficient
n	number of foils
w	width of foils, m
w_b	width of side stripes, mm
W_r	mass of PSR core, kg
L	length of flow passage, m
Lz	total length of PSR core, m
Nu	Nusselt number
P	wetted perimeter of channels, mm
Pr	Prandtl number
Re	Reynolds number
U_t	total-heat-transfer coefficient, W/(m^2 °C)
Wz	total width of PSR core, mm
h_1, h_2	heat convection coefficient, W/(m^2 °C)
δ	thickness of foils, mm
δ_b	thickness of side stripes, mm
δ_d	thickness of end plates, mm
k	heat conductivity, W/(m °C)
υ	kinematical viscosity, m^2/s
ρ_m	density of foils, kg/m^3

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