THERMAL CHARACTERISTICS OF SPRINGY SHAPE COIL PACKED BED IN ROTATING REGENERATORS +

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Abstract:

The heat storing / transporting mass of the rotating regenerators in power plants is usually made of corrugated plates. Corrugations serve to provide greater turbulence and thus film heat transfer coefficient as well as providing sufficient stiffness to airflow passages. The metal plates are usually made of different sizes, pitches and profiles. The thermal characteristic and pressure drop of alternative (springy shape coil packed bed) capable of performing the same thermal duty is presented in this study. Coil elements cross-section diameter ranging from (dc=2mm) to (dc=8mm) with springy shape of the coil elements diameter ranging from (ds=50mm) to (ds=100mm) with pitch distance twice the coil element diameter are considered for the packed bed. The performance (film heat transfer coefficient, the pressure drop, thermal efficiency) of the pack is investigated computationally and compared to the plate matrix performance. It is found that the heat capacity and the film heat transfer coefficient of the alternative pack for most sizes of (dc & ds) are greater than that of the original pack and cause an increase in the thermal efficiency. although the heat transfer surface area of the alternative pack is less than that of the original pack. It is found also that the pressure drop in the alternative pack is much less than that of the original pack for all sizes of (dc & ds).

المستخلص

الكتلة (الخازنة / المصدرة) للحرارة في المسترجعات الحرارية الدوارة في محطات توليد الطاقة الكهربائية تصنع عادة من صفائح مضلعة. المضلعات في الصفائح تعمل على زيادة الدوامات وبالتالي زيـــادة معامـــل انتقـــال الحرارة فضلاًص عن توفيرها ثباتاً وقوة لممرات الهواء. الصفائح المعدنية تصنع عادة بمختلف المواصفات الهندسية وبأشكال مختلفة. الخصائص الحرارية والانخفاض بالضغط الناتج من استخدام بدائل من الحشوات بشكل ملف معدني التي تعطي الواجبات الحرارية نفسها هو محور هذه الدراسة. استخدمت لهذا الغرض حشوات حرارية بـــشكل ملـــف قطر سلكه يتراوح بين (dc=2mm) الى (dc=8mm) مع قطر لف يتغير من (ds=50mm)الى (ds=100mm) وبخطوة لف مقدارها ضعف قطر السلك. تم حساب معامل انتقال الحرارة والانخفاض بالضغط والكفاءة الحرارية لكل حشوة ذات قطر سلك وقطر لف معين وقورنت النتائج مع مثيلتها في حشوة الصفائح المـــضلعة. وجـــد أن الخـــزن الحراري ومعامل انتقال الحرارة للحشوات البديلة لمعظم قياسات الملف هو اكبر مما هو عليه في حشوات الـــصفائح المضلعة مما أدى الى زيادة الكفاءة الحرارية للمسترجع الحراري، بالرغم من ان مساحة التبادل الحراري للحشوات البديلة لجميع المقاسات هي اقل من مثيلتها في الحشوات ألاصلية. لقد وجد أيضا أن الانخفاض بالضغط الناتج عـــن

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مرور الهواء خلال الحشوات موضوع الدراسة لجميع المقاسات اقل بكثير عن تلك الناتجة من حـــشوات الـــصفائح المضلعة.

Introduction:

The air heaters (regenerators of power plants) consist of corrugated plate packs. The corrugated sheets metal (iron) may weigh several tons. Due to the adverse thermal environment, the metal is subjected to corrosion, which may result in the regular renewal once every two or three year. At the end of its life time, the sheet metal pack becoms incapable of supporting itself resulting in severe blockage of the air flow passage. The use of steam to clean the pack and the existence of water vapor, nitrogen sulphur oxides appear to be the main culprits in the corrosion of the pack. The searches for alternative pack appear to be worth while effort.

Alternative packs may work just as well if the heat transfer parameters affecting the performance of the pack are comparable with those of the original pack. These parameters are:

1- Total surface area of the pack material through which heat is exchanged.
2- The heat capacity rate of the pack material.
3- Pressure drop in the flue-gas side and fresh-air side of the regenerator that occurs due to the geometry of the pack used.
4- The convection heat transfer coefficient within the pack may be influenced by the pack geometry.

The Mathematical Model:

Referring to an original pack of the rotating regenerators of a power plant which is made of corrugated plates[1,2],the thermal performance and the pressure drops equations and results obtained ak quoted from to ref.[3].

A set of equations represents the different parameters used to calculate the thermal

$$* \quad \text{surface area of the coil element} = \frac{p^{3} ds \quad D}{2} ---------(1)$$

performances and pressure drop for a springy shape coils pack (Fig.1) listed as follows:-
for each ring diameter (D) from out side diameter (Do)to inside diameter (Di) of the drum,

$$* \text{Mass of the coil element} = \frac{r_m \, p^2 \quad dc \quad ds \quad D}{8} ------------(2)$$

each diameter step (ds).
for each ring diameter (D) as for surface area.

*The following expression for heat transfer coefficient in regenerators-cross flow which were helically coiled in several layers which were aligned above on another is given by Grimision [4]. Grimision correlates the test measurements of Pierson and Huge for an in-line arrangement.

$$Nu = 0.34 \; fa \; \mathrm{Re}^{0.6} \; \mathrm{Pr}^{0.3} -------------(3)$$

$$where \quad fa = 1 + (a + \frac{7.17}{a} - 6.52)(\frac{0.266}{(b-0.8)^2} - 0.12)\sqrt{\frac{1000}{\mathrm{Re}}}$$

$$where \quad a = \frac{Sq}{d} \quad \& \quad b = \frac{Sd}{d}$$

d = diameter of the coil

*The pressure drop measurement equation is give by Jakop[5]

$$\Delta P = n\, j\, \frac{r u^2}{2} - - - - - - - - - - - - (4)$$

where f is dimenssion less quantity $\quad j = \mathrm{Re}^{-0.16}\,[1 + \frac{0.47}{(a-1)^{1.08}}]$

n = No. of the rows of coil lying behind the other in the direction of flow.

<u>Calculation Procedure:</u>

A heat balance was made for an element in the matrix and a transformation of coordinate [4,5] an element in :

$z = \frac{h\ A}{C_f\ \dot{m}_f}$, $h = (\frac{h\ A}{C_m\ M_m})\, t$ where introduced in the differential equations yield :–

$$\left(\frac{\partial t_f}{\partial z}\right)_h = t_m - t_f - - - -(5) \quad , \quad \left(\frac{\partial t_m}{\partial h}\right)_z = t_f - t_m - - - -(6)$$

A computer program was built with a step by step calculations performed over the domain set by (ζ = 0-1) , (η = 0-1) when ζ = 1 the reduced period is defined as :

$$\Lambda = \frac{h.A}{\dot{m}_f.C_f} - - - -(7) \quad , \quad \Pi = \frac{h.A.P}{M_m.C_m} - - - -(8)$$

The thermal efficiency of the regenerator ($\eta_{reg.}$) is calculated as:

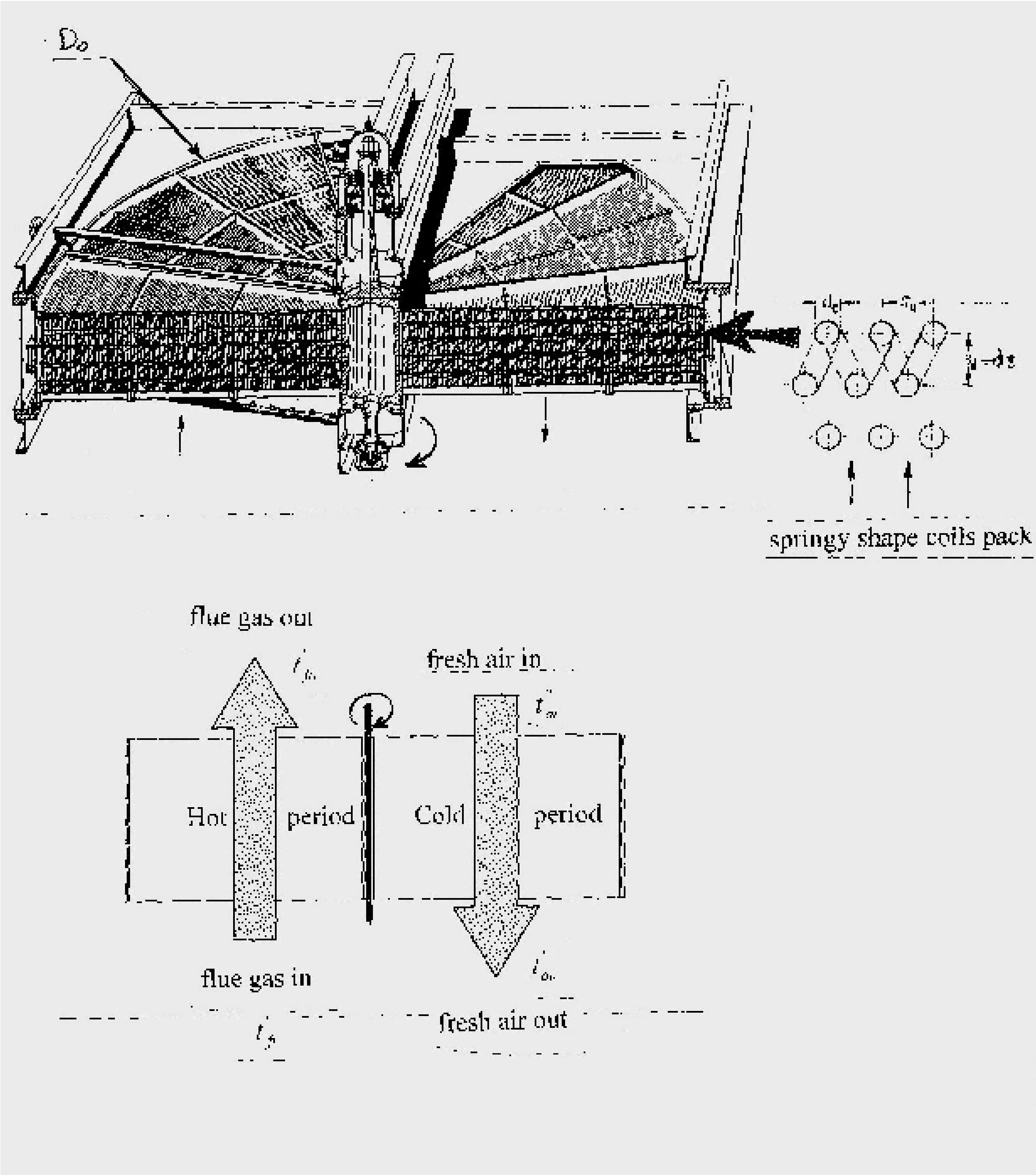

Fig.(1) The air-heater (Regenerator of the power plants)

$$h_{reg.} = \frac{t'_{fi} - t'_{fo}}{t'_{fi} - t''_{fi}} ----(9)$$

And the pressure losses were evaluated for different reduced periods. The effect of heat transfer coefficient with coil diameter, the heat transfers surface area, and the matrix total mass were evaluated [6,7,8].

<u>Results and Discussion:</u>

Tables (1) to (7) show a summary of different sizes of coil elements cross-section diameter (dc) ranging from (2mm) to (8mm), combined with different sizes for the coil ring diameter (ds) ranging from (50mm) to (100mm). In all cases, the pitch distance was considered as twice the coil element diameter. The tables represent the thermal performance of seven kinds of springy shape coils packed bed. The heat transfer coefficient for the hot and cold period, heat transfer surface area and total mass of the pack matrix, the pressure drop results in the hot and cold period for each case, average flue gas out temperature, average fresh air out temperature and the thermal efficiency for each case, are represented in these tables

Table (1) dc=2mm

ds (mm)	A m^2	W Kg	h_f $W/m^{2o}C$	h_a $W/m^{2o}C$	Pd_f N/m^2	Pd_a N/m^2	π	t_{fo} ^oC	t_{ao} ^oC	η_{reg}. %
50	6957	27377	239	219	224	261	1.099	130	325	82.1
60	5929	23333	250	228	267	215	1.148	134	321	80.7
70	5159	20304	255	233	226	182	1.170	139	316	78.9
80	4632	18228	258	235	200	161	1.183	143	312	77.5
90	4098	16128	259	236	174	140	1.188	148	306	75.7
100	3572	14059	259.5	237	149	120	1.190	155	249	73.2

Table (2) dc=3mm

ds (mm)	A m^2	W Kg	h_f $W/m^{2o}C$	h_a $W/m^{2o}C$	Pd_f N/m^2	Pd_a N/m^2	π	t_{fo} ^oC	t_{ao} ^oC	η_{reg}. %
50	6824	40280	220	200	331	267	0.673	133	322	81.1
60	5842	34484	221	202	269	217	0.676	139	316	78.9
70	5089	30040	221	202	226	182	0.676	145	310	76.8
80	4302	25397	220	201	184	149	0.674	153	301	73.9
90	4067	24008	220	201	171	138	0.674	156	298	72.9
100	3598	20943	220	200	146	117	0.672	163	290	70.4

Table (3) dc=4mm

ds (mm)	A m^2	W Kg	h_f $W/m^{2o}C$	h_a $W/m^{2o}C$	Pd_f N/m^2	Pd_a N/m^2	π	t_{fo} ^oC	t_{ao} ^oC	η_{reg}. %
50	6436	50658	197	180	327	263	0.451	139	315	78.9
60	5476	43097	197	180	260	210	0.452	146	307	76.4
70	4756	37430	196	180	215	173	0.451	153	300	73.9
80	4266	33577	196	179	186	150	0.449	159	294	71.8
90	3748	29500	195	178	158	127	0.447	166	287	69.3
100	3504	27579	195	178	145	117	0.447	170	283	67.9

Table (4) dc=5mm

ds (mm)	A m^2	W Kg	h_f $W/m^{2o}C$	h_a $W/m^{2o}C$	Pd_f N/m^2	Pd_a N/m^2	π	t_{fo} ^oC	t_{ao} ^oC	η_{reg}. %
50	6315	62124	185	169	343	277	0.339	143	311	77.5
60	5396	53092	183	167	270	217	0.336	150	303	75
70	4691	46155	182	166	220	177	0.333	157	295	72.5
80	4211	41429	181	165	189	152	0.331	164	289	70
90	3720	36600	179	164	160	129	0.329	171	281	67.5
100	3480	34241	179	163	146	118	0.328	175	277	66.1

Table (5) dc=6mm

ds (mm)	A m^2	W Kg	h_f $W/m^{2o}C$	h_a $W/m^{2o}C$	Pd_f N/m^2	Pd_a N/m^2	π	t_{fo} ^oC	t_{ao} ^oC	$\eta_{reg.}$ %
50	6215	73375	175	160	364	293	0.268	145	308	76.8
60	5319	62796	172	158	282	227	0.264	154	299	73.6
70	4628	54641	171	156	227	183	0.261	161	291	71.1
80	4157	49073	169	155	194	156	0.259	168	284	68.6
90	3673	43369	168	153	163	131	0.256	175	276	66.1
100	3437	40582	167	152	148	120	0.255	180	272	64.3

Table (6) dc=7mm

ds (mm)	A m^2	W Kg	h_f $W/m^{2o}C$	h_a $W/m^{2o}C$	Pd_f N/m^2	Pd_a N/m^2	π	t_{fo} ^oC	t_{ao} ^oC	$\eta_{reg.}$ %
50	5855	80647	167	153	361	291	0.219	150	302	75
60	4994	68780	164	150	274	221	0.215	159	293	71.8
70	4566	62893	163	148	236	190	0.213	165	287	69.6
80	4123	56785	161	147	200	161	0.211	171	281	67.5
90	3646	50228	159	145	167	134	0.208	179	272	64.6
100	3415	47033	158	144	152	122	0.207	183	268	63.2

Table (7) dc=8mm

ds (mm)	A m^2	W Kg	h_f $W/m^{2o}C$	h_a $W/m^{2o}C$	Pd_f N/m^2	Pd_a N/m^2	π	t_{fo} ^oC	t_{ao} ^oC	$\eta_{reg.}$ %
50	5765	90747	162	148	384	310	0.186	152	300	74.3
60	4923	77494	158	144	287	231	0.181	162	290	70.7
70	4255	66979	155	141	225	181	0.178	171	280	67.5
80	3816	60064	153	140	188	152	0.176	178	273	65
90	3601	56687	152	132	171	138	0.174	182	269	63.6
100	3113	49003	150	137	139	112	0.172	192	258	60

Three figures were plotted using the data of the tables (1 to 7). They show the effect of each size of springy shape coils with heat transfer surface area, the total matrix mass and the heat transfer coefficient. These factors represent the main factors which affect the heat capacity of the packed bed and the heat transfer phenomena.

Fig.(2) shows the average heat transfer coefficient ($W/m^{2.o}C$) versus coil element diameter (dc) of the heat storing mass for each ring diameter of the coil (ds). The figure shows that the heat transfer coefficient is reduced as the diameter of the coil element (dc) becomes larger for all sizes of (ds) as shown. It is shown that heat transfer coefficient for all sizes of springy shape coil packed bed is much higher than that of the corrugated plate heat storing mass [3], due to the efficient contact between the air and the material which exchanged heat in the alternative pack.

Fig.(3) shows that the total heat transfer surface area formed by all sizes is less than the heat transfer surface area of the corrugated plates. However, the figure shows that the alternative springy shape coil of (dc=2mm) & (ds=50mm) from a packed bed of heat transfer surface area which is nearest to the surface area formed by the corrugated plates packed bed [3], this surface area drops as (ds) increases.

Fig. (4) shows that most of the steel springy shape coil pack forms a denser regenerator pack than that of corrugated plates [3] in the rotary regenerator except for the sizes of small (dc) with small (ds). It forms a lighter packed bed than that of the corrugated plates as it is clear from the figure. Weight limitation set by the design of rotary regenerator may make this factor critical when we treat large sizes of (dc) & (ds) coil pack

The pressure drop throughout the regenerator pack is an important limitation. A set of values consisting pressure loss (ΔP) in (N/m^2) in the springy coil packed bed for different combination of coil diameter (dc) and ring diameter (ds) is formed.

Fig. (5) shows that any combination of (dc) and (ds) causes a packed bed of less pressure loss than that caused by the corrugated plate packed bed [3]. In the same time, whenever (ds) increases, pressure loss shows a decrease in its magnitude.

A nondimensional reduced period (Π) which is equal to (hAP/M_mC_m) was used, so that, the main parameters affecting the heat transfer in the pack-material can be lumped together. The thermal efficiency of the regenerator ($\eta_{reg.}$) was also evaluated. Generation of a set of values of ($\eta_{reg.}$) for each value of (Π), and for each size of (dc) and (ds) diameters which forms the alternative packed bed facilitas the comparison.

Fig. (6) shows reduced period (Π) versus the coil diameter (dc) for each ring diameter (ds), so that, it can be referred to as the diameter of the coil elements (dc) with spring shape ring diameter (ds) instead of the reduced period (Π) in the discussion of Fig.(7).

Fig.(7) shows the thermal efficiency of the regenerator versus the reduced period (Π) for different sizes of rings diameter (ds). It is clear that for small (ds) between (50mm-60mm), the thermal efficiency is much better than that of the corrugated plates pack [3], and for the other sizes, the thermal efficiency is either within or better than that of the corrugated plates pack. Only a small range of reduced period for large ds between (ds= 90mm-10mm) shows less thermal efficiency compared with that of the corrugated plates packed bed.

Conclusions:

Although the springy shape coil packed bed presents a heat transfer surface area less than that of the corrugated plate packed bed, other factors which affect the heat capacity and heat transfer of the pack in the springy coil element heat storing mass are better than the original one. So the combination of all these factors which is shown by the dimensionless factor known as reduced period shows that the thermal efficiency of the regenerator of this kind is much better than the old one. Heavy weight of springy shape coil pack of large sizes (dc&ds) puts a limitation to these sizes. It can be assumed that the coil element diameter (dc) which can be used must be within (2mm-3mm) and the springy shape ring diameter (ds) must be within (50mm-60mm). The pressure drop for all sizes of (dc&ds) for this packed-bed is much less than that of the original one and this can assumed to be a very good advantage.

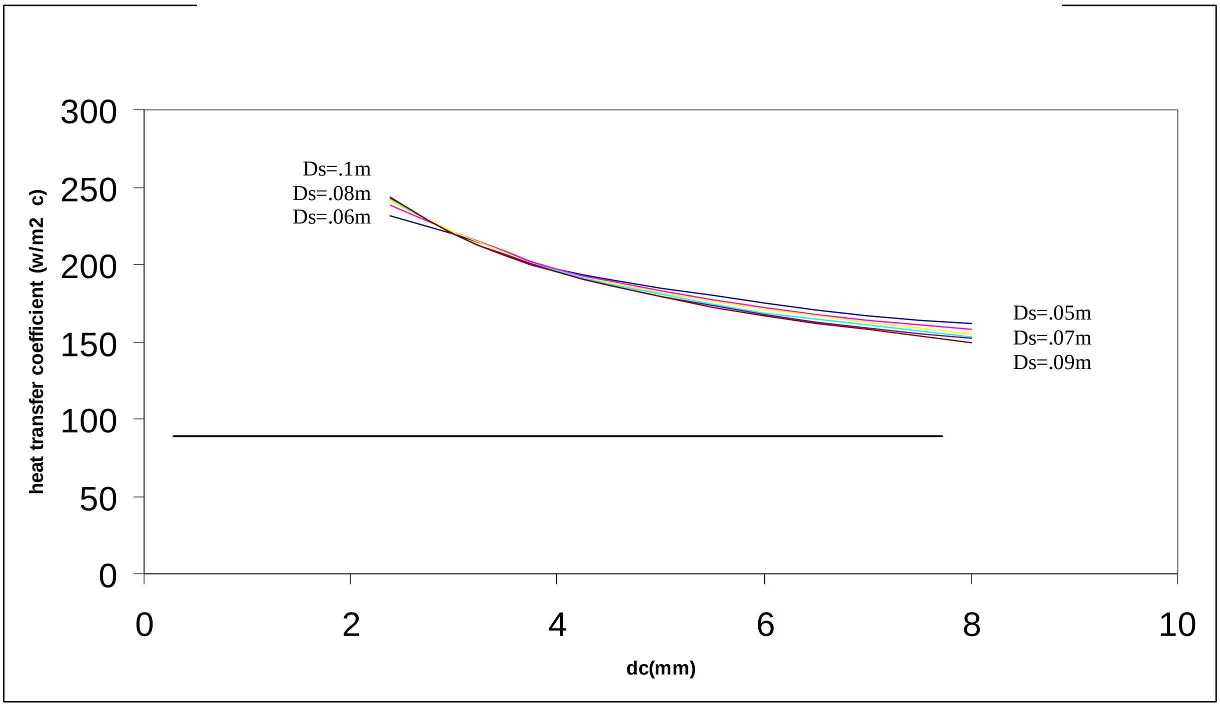

Fig (2)*Heat transfer coefficient versus coil diameter dc (mm)for each ringe diameter ds(m)*

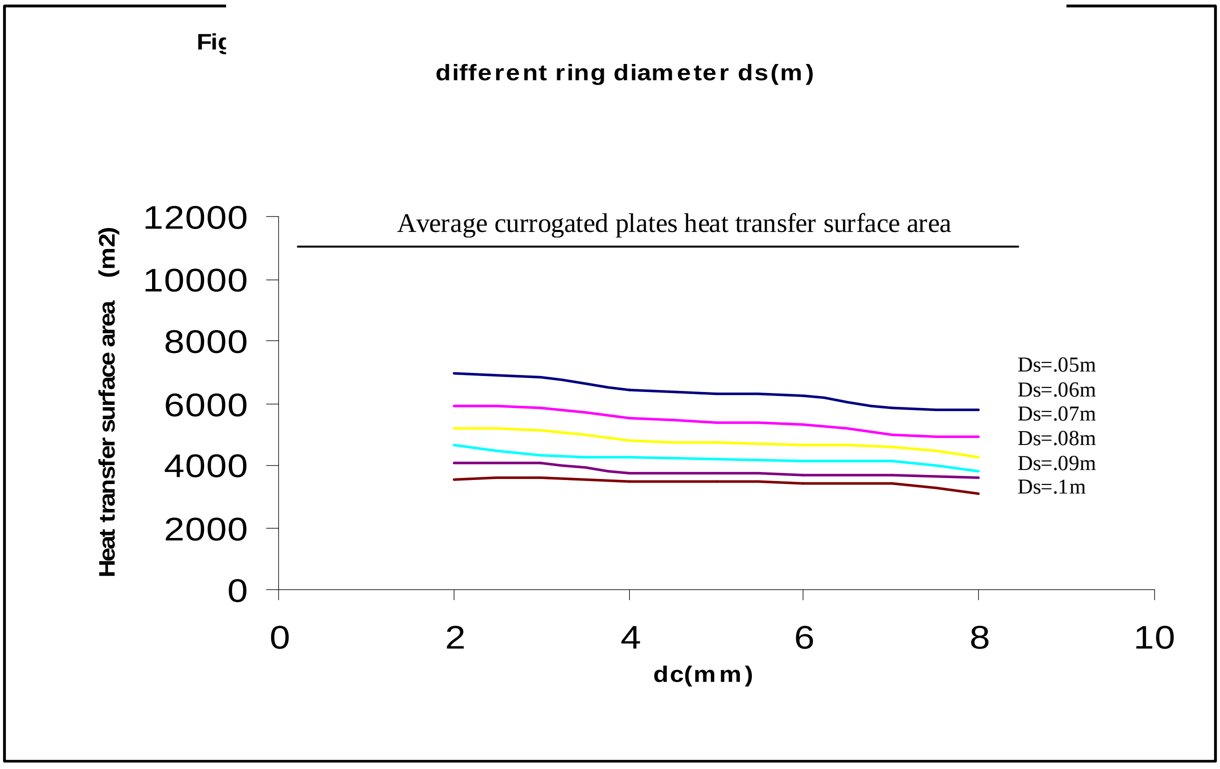

Fig (3)*Heat transfer surface area versus coil diameter dc (mm)for different ring diameter ds(m)*

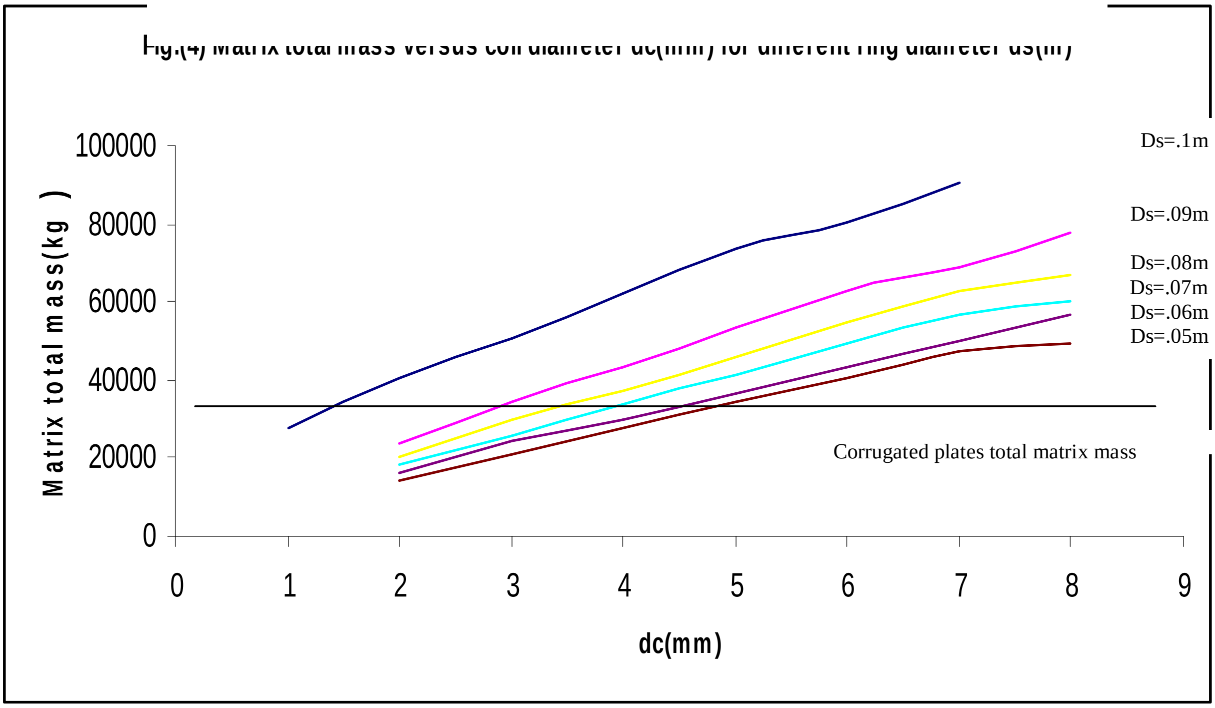

Fig (4) *Matrixtotal mass versus coil diameter dc (mm)for different ring diameter ds(m)*

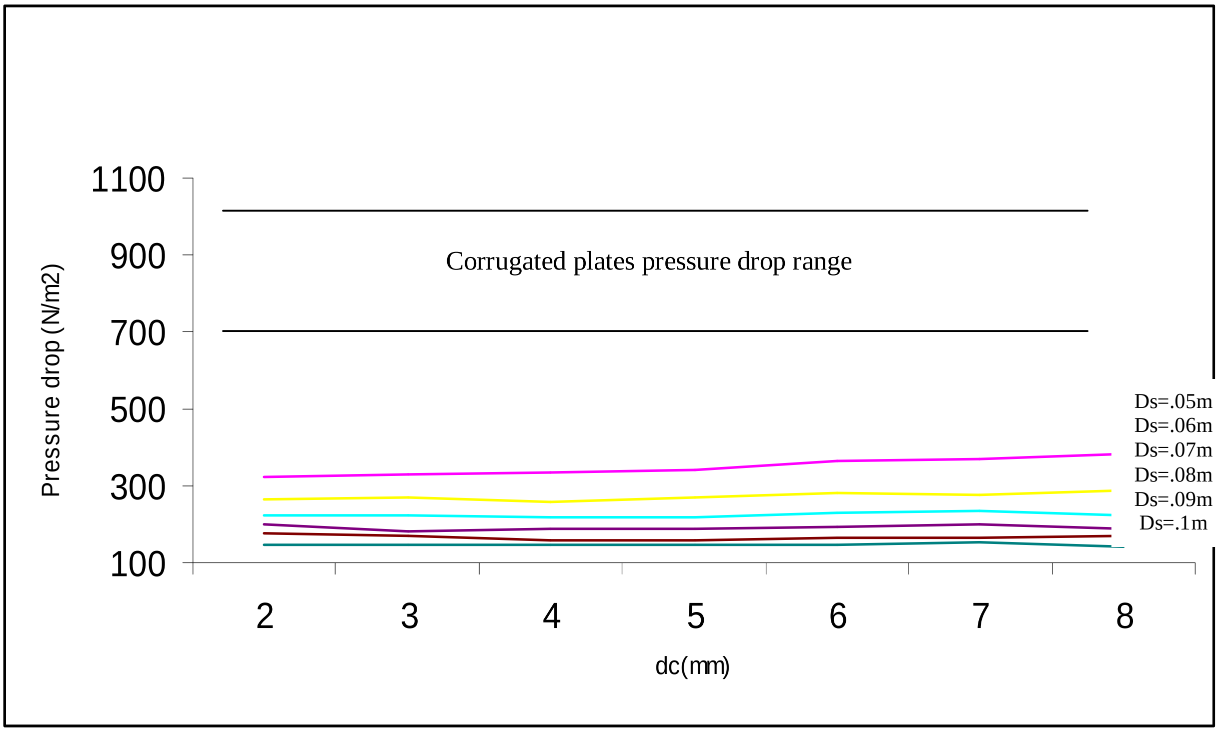

Fig (5) *Pressure loss (N/m2) versus coil diameter dc (mm)for different ring diameter ds(mm)*

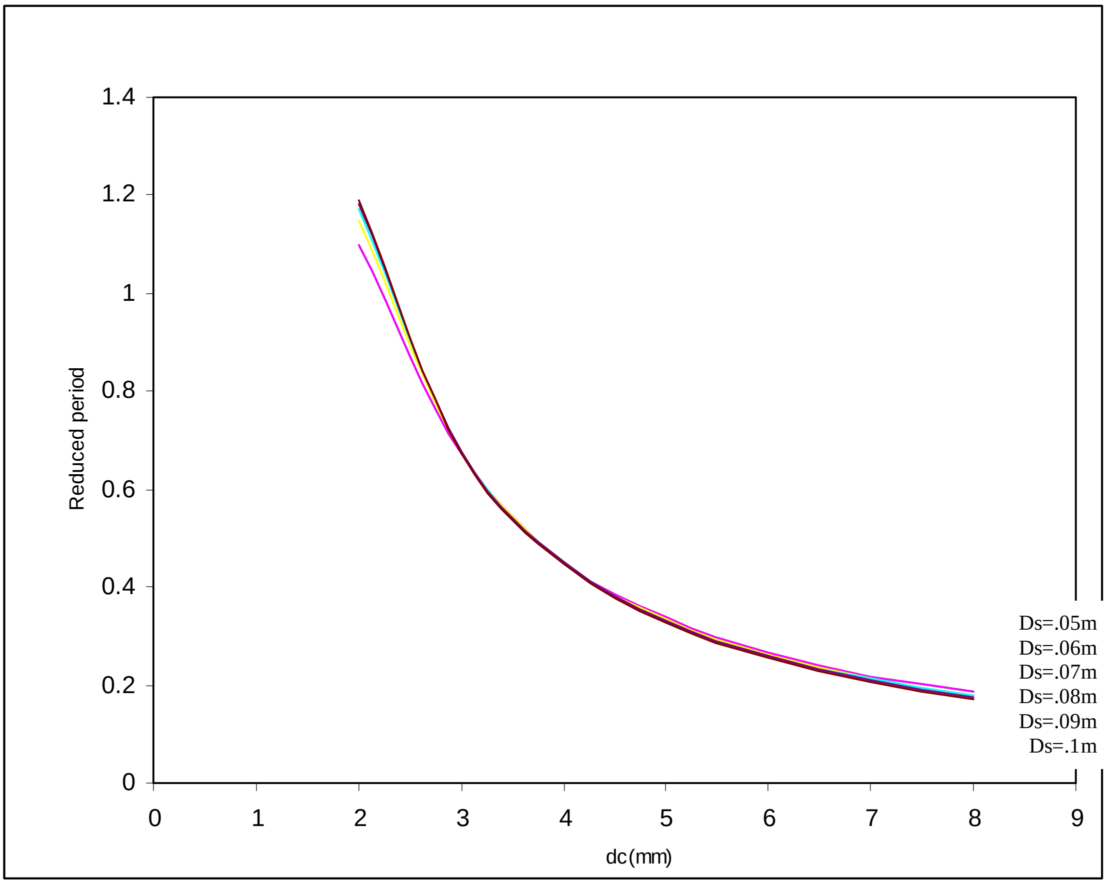

Fig (6) *Reduced period versus coil diameter for each ring diameter ds(m)*

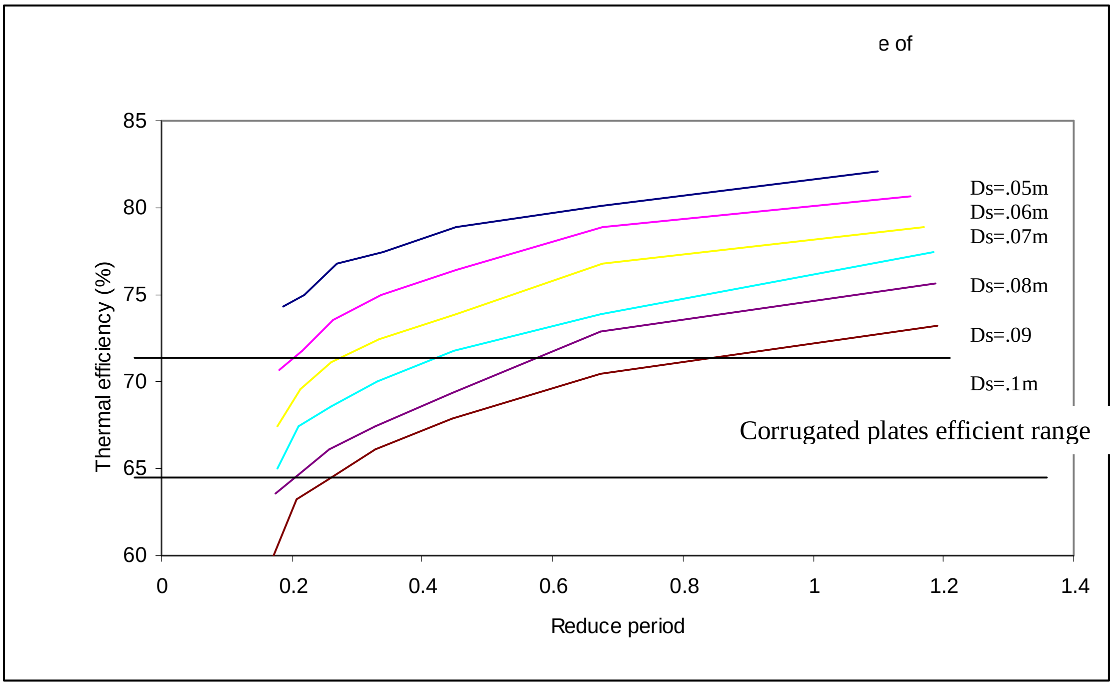

Fig (7) *Regenerator thermal efficiency versus reduced period for different size of ring diameter ds(mm)*

Nomenclature:

dc *Coil element diameter (m)*

ds *Springy shape diameter (m)*

Do *Out side diameter of the regenerator drum = 6.06m (Al-Dura power station air heater dimentions.)*

Di Inside diameter of the regenerator drum=1.0m (Al-Dura P.S.dim.)

r_m Mass density of matrix material (kg/m^3)

A Total heat transfer surface area of the springy shape packed-bed (m^2)

C_f Specific heat of the fluid flow (air) at constant pressure (J/kg K)

C_m Specific heat of the packed-bed material (J/kg K)

$\dot{m}$ Air mass flow rate (kg/s)

M_m Total mass of the pack material (kg)

P Duration of period (s)

t Temperature (K)

h Average heat transfer coefficient (W/m^{2o}C)

Pd Average pressure drop (N/m^2)

t_{fo} Average out temperature of the flue gas (^{o}C)

t_{ao} Average out temperature of the fresh air (^{o}C)

Greek letters:

ζ	Nondimentional axial distance
η	Nondimentional time
η_{reg}	Thermal efficiency of the regenerator
Π	Reduced period (dimensionless parameter)
Λ	Reduced length (dimensionless parameter)
τ	Time (s)

Subscripts:

f	refers to flue gas
a	refers to fresh air
i	refers to inlet
o	refers to outlet
m	refers to the material of the pack
reg.	Regenerator
'	refers to hot period
''	refers to cold period

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