Comparing the Tube Fin Heat Exchangers to Metal Foam Heat Exchangers for Geothermal Applications

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This paper examines the application of two different heat transfer augmentation techniques to improve the performance of an air-cooled heat exchanger. The conventional finned-tube design is compared with a modern technique being the application of a metal foam heat exchanger applied as a layer to the outer surface of the tube. Both designs improve the heat transfer rate from the condensing fluid flowing in the tube bundle albeit at the expense of a higher pressure drop compared to the bare tube as our reference case. Considering the heat transfer enhancement as the benefit and the excess pressure drop as the cost, the two cases are compared against each other. In order to achieve this goal, results from two different sources have been compared being ANSYS-Fluent and ASPEN B-JAC. A number of correlations are also proposed to predict the cost (excess pressure drop) and the benefit (heat transfer augmentation) of the extended surface.

Introduction

Most of the geothermal resources of Australia are located in arid areas where there is not enough water to feed wet cooling towers to absorb the cycle waste heat. Air-cooled condensers provide the only economic choice in such places where the cycle fluid condenses inside the tubes cooled by air. The tubes have external fins to increase the air-side heat exchange surface. Fins improve the heat transfer performance but at the same time lead to higher pressure drop compared to bare tubes. As such, there always is a trade-off between these two opposing effects where the main goal is to remove the waste heat from the condenser.

Metal foams, an emerging technology in the field of heat exchangers, benefit from such advantages as low-density, high area/volume ratio, and high strength structure. Therefore, they have been applied in a variety of applications including cryogenics, combustion chambers, cladding on buildings, strain isolation, buffer between a stiff structure and a fluctuating temperature field, petroleum reservoirs, compact heat exchangers for airborne equipments, high power batteries, compact heat sinks for power electronics and electronic cooling, heat pipes and sound absorbers (Mahjoob and Vafai 2008). This study explores a comparison between thermo-hydraulic performance of finned-tubes and metal foam heat exchangers with specific attention being paid to the price, weight and manufacturing structure as a basis for future work.



Figure 1: Samples of metal foam heat exchanger and tube fin heat exchanger

Finned-Tube Heat Exchangers

A finned-tube heat exchanger is designed by the well-known commercially available engineering software ASPEN B-JAC for an air-cooled heat exchanger, as indicated by Table 1. This table presents a sample of our results for a binary cycle with Isopentane as the working fluid which is cooled by air in a geothermal power plant. Based on an efficiency of about 15%, 283 MW of heat should be dumped so that 50 MWe can be generated; see also (Ejlali et al 2008). Further details of the air-cooled heat exchanger, including fin thickness, type, and number density are presented in Tables 1 and 2 where the tube bundle configuration is illustrated in Figure 2.

Metal Foam Heat Exchangers

Performance of a metal foam-covered single tube as a representative, in cross-flow is examined numerically as illustrated by Figure 3 where the geometry and the applied mesh system is presented. As mentioned earlier, the commercially available CFD software Fluent is used to solve the full set of governing equations for different samples of metal foams (Calmidi and Mahajan 2000).

Similar to (Hooman and Gurgenci 2010), the thermo-hydraulic performances of the two different designs, finned-tube and metal foam-covered heat exchangers, are compared under similar conditions.

Summary and Conclusion

It is expected that metal foams heat exchangers have higher heat transfer rates compared to finned-tube ones. At the same time, metal foams can cause higher pressure drop. Interestingly, for a specific case where the same boundary conditions have been set for a metal foam covered tube and finned tube (air velocity = 3.34m/s, air temperature = 308K, tube temperature = 320K), according to our numerical results, the former is associated with 10% higher heat transfer rate at the same pressure drop. It is expected that an optimization study can further increase the heat transfer of metal foams so that the heat removal form a binary cycle in a geothermal power plant can significantly be improved with less parasitic losses compared to the existing technology.

References

Calmidi, V. V. and R. L. Mahajan (2000). "Forced convection in high porosity metal foams." Journal of Heat Transfer 122(3): 557-565.

Ejlali, A., Hooman, K., "A comparative study on dry cooling of different working fluids for geothermal applications," AGEC 2008, Melbourne, Australia.

Mahjoob, S. and K. Vafai (2008). "A synthesis of fluid and thermal transport models for metal foam heat exchangers." International Journal of Heat and Mass Transfer 51(15-16): 3701-3711.

Hooman, K. and H. Gurgenci (2010) Different heat exchanger options for natural draft cooling towers to be presented in World Geothermal Congress, Bali, Indonesia.

Table 1: The result of ASPEN B-JAC

Air-Cooled Heat Exchanger Specification Sheet

1	Company:						
2	Location:						
3	Service of Unit:		Our Reference:				
4	Item No.:		Your Reference:				
5	Date:	Rev No.:	Job No.:				
6	Size & Type	6243 / 1073155Type	Induced		Number of Bays	219	
7	Surf/Unit-Finned Tube	612786.1 m²			Bare Tube	56306.8	m²
8	Heat exchanged	283127000 W			MTD, Eff	15.22	℃
9	Transfer Rate-Finned	30.4 Bare, Service	330.4		Clean	354.3	W/(m² K)
10	**PERFORMANCE DATA - TUBE SIDE**						
11	Fluid Circulated					In/Out	
12	Total Fluid Entering	kg/s 858		Density, Liq	kg/m³	592.07/592.07	
13		In/Out		Density, Vap	kg/m³	2.71/2.71	
14	Temperature	℃ 46.85/46.85		Specific Heat, Liq	kJ/(kg K)	2.376/2.376	
15	Liquid	kg/s 857.9901/858		Specific Heat, Vap	kJ/(kg K)	1.766/1.766	
16	Vapor	kg/s 0.01/		Therm. Cond, Liq	W/(m K)	0.099/0.099	
17	Noncondensable	kg/s /		Therm. Cond, Vap	W/(m K)	0.017/0.017	
18	Steam	kg/s /		Freeze Point	℃		
19	Water	kg/s /		Bubble / Dew point	℃	/ 45	
20	Molecular wt, Vap	/		Latent heat	kJ/kg	330	
21	Molecular wt, NC			Inlet pressure (abs)	bar	1	
22	Viscosity, Liq	mPa s 0.182/0.182		Pres Drop, Allow/Calc		0.4/ 0.001	
23	Viscosity, Vap	0.009/0.009		Fouling Resistance	m² K/W		
24	**PERFORMANCE DATA - AIR SIDE**						
25	Air Quantity, Total	24000 kg/s		Altitude		m	
26	Air Quantity/Fan	97.545 m³/s		Temperature In	25	℃	
27	Static Pressure	25.26 mmH²O		Temperature Out	36.74	℃	
28	Face Velocity	3.34 m/s Bundle velocity	11.1 kg/s/m²	Design Ambient		℃	
29	**DESIGN-MATERIALS-CONSTRUCTION**						
30	Design pressure	1.448 bar	Test Pressure	Code	Design temperature	78.89	℃
31	**TUBE BUNDLE**		**Header**		**Tube**		
32	Size	6243	Type Plug		Material	CS	
33	Number/bay	2	Material		Specifications	Welded	
34	Tube Rows	5	Passes	1	OD	62 Min Thk.	1.65 mm
35	Arrangement		Plug Mat.		No./Bun	110 Lng	6 m
36	Bundles	2 par 1 ser	Gasket Mat.		Pitch	106.35 / 92.1	Staggered
37	Bays	219 par 1 ser	Corr. Allow.	3.18 mm	**FIN**		
38	Bundle frame	Galvanized steel	Inlet Nozzle (2)	50.8 mm	Type	Embedded	
39	**MISCELLANEOUS**		Outlet Nozzle(2)	50.8 mm	Material	CS	
40	Struct. Mount.		Special Nozzles		OD	100 Tks	0.91 mm
41	Surf.Prep		Rating		No.	197 #/m Des Temp	℃
42	Louvers		TI PI		Code		
43	Vibration Switches		Chem Cleaning		Stamp	Specs API 661	
44	**MECHANICAL EQUIPMENT**						
45	Fan,Mfr., Model		Driver, Type		Speed Reducer, Type		
46	No./Bay	1 RPM 134.67	Mfr.		Mfr.&Model		
47	Dia. mm	4572 Blade(s) 18	No./Bay		No./Bay		
48	Pitch	1.54 Angle	RPM		Rating		hp
49	Blade(s)	4572 Hub 2286	Enclosure		Ratio		
50	hp/Fan	32.83 Min Amb	V/Phase/Hz	/ /	Support		
51	Control Action on Air Failure-				Louvers		
52	Degree Control of Outlet Process Temperature						
53	Recirculation				Steam Coil		
54	Plot Area	m²	Drawing No.	Wt.Bundle	7889.5 Wt.Bay	18042	kg
55	Notes:						
56							
57							
58							

Table 2: Mechanical details of tubes and fins

Tube material		Carbon Steel	Fin material		
Tube length	m	6	Fin type		Embedded
Tube OD	mm	62	Fin OD	mm	100
Tube wall thickness	mm	1.65	Fin thickness	mm	0.91
Tube pitch face row	mm	106.35	Fin density	#/m	197
Tube pitch rows deep	mm	92.1	Fin segment width	mm	
Tube pattern		Staggered			
Pass type					
Area ratio Ao/Ai		11.49			

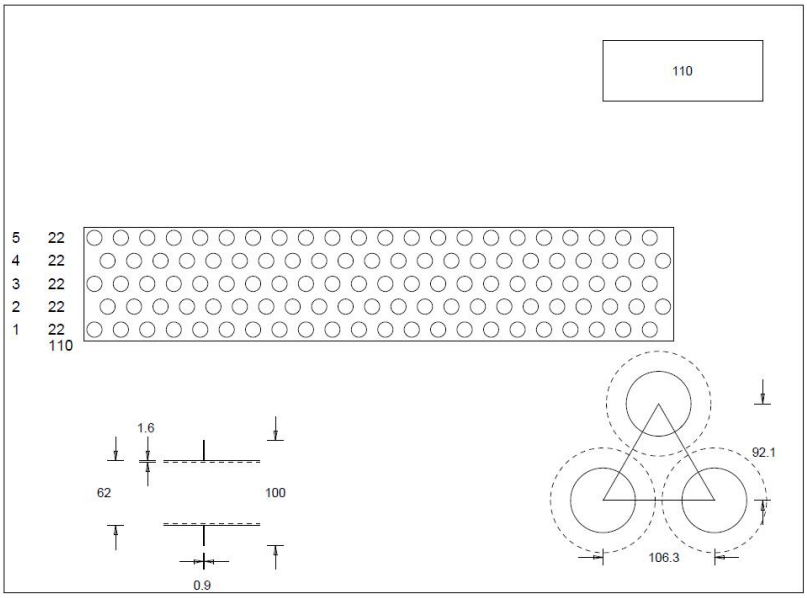

Figure 2: Mechanical details of tube layout

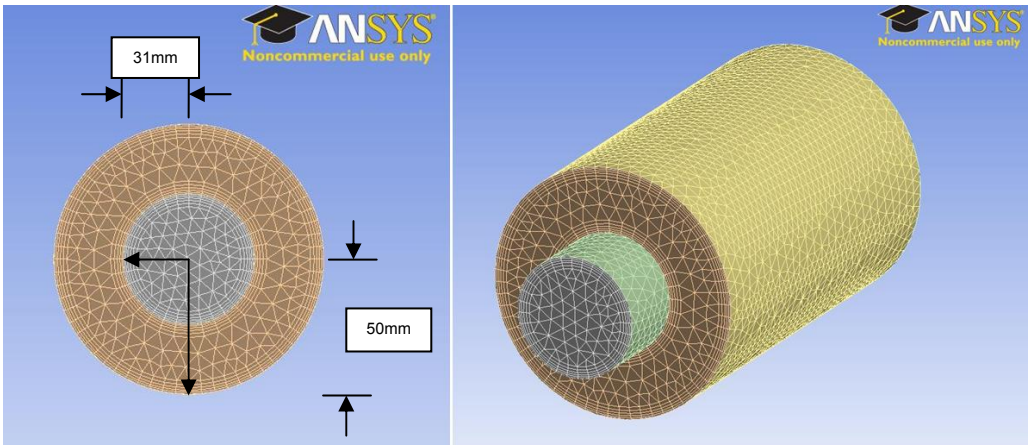

Figure 3: The metal foam-covered single tube in 2D and 3D views (the generated mesh in the flow region has not been shown for the visibility proposes).