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Revision Memo

12/01	Reaffirmation of previous revision of DP IX-H, December, 1995, with minor editorial changes.
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SCOPE

This section presents a brief description and a single phase calculation procedure for double pipe and multitube hairpin heat exchangers.

REFERENCES

GLOBAL PRACTICE

GP 6-2-1 Double Pipe and Multitube Hairpin Heat Exchangers

OTHER LITERATURE

Hagner, R. C., *Petro/Chem Engineer*, 27, August 1968

Kern, D. Q., *Process Heat Transfer*, McGraw Hill, New York 1950

McDonough, M. J., *Chemical Engineering*, July 20, 1987

EQUIPMENT TYPES AND APPLICATIONS

Double pipe and multitube heat exchangers consist of one or more pipes or tubes inside a pipe shell. The units usually consist of two straight tube lengths connected at one end to form a U or "hairpin". A sketch of a typical hairpin section is shown in **Figure 1**. The two straight shell lengths are connected by a return bend cover referred to as the "bonnet". These exchangers are also available without the hairpin - i.e., a straight section. The use of the hairpin construction rather than a straight length allows the ability to handle differential thermal expansion. One advantage of Hairpins is that the tube bundle is removed from the bonnet end which does not require the disassembly of the piping connections on the other end. Another advantage is that because of the large U-bend diameters even on the smallest U's, it is possible to use a flexible cleaning tool to clean the inside of the tubes. This is difficult to do in the inner tubes of a TEMA type shell-and-tube exchanger. Although some double pipe sections have bare tubes, the majority have longitudinal fins on the outside of the inner tubes. The fins are sometimes slotted to provide enhancement to the outside heat transfer coefficient.

Hairpins are available in all the common materials of construction and can be built to the most severe design temperature and pressure requirements expected in petroleum refining. Also, the tubes, fins, and shell can be of different materials. However, since the fins are normally welded to the tubes, the fin and tube materials must be compatible.

The use of fin tubes in hairpin sections is normally economical if the annular (shell side) heat transfer coefficient is less than 75% of the tube side coefficient. This is not a hard and fast rule because the break even point is a strong function of the annular heat transfer coefficient and fin material, both of which affect the fin efficiency. The fin efficiency increases with decreasing annular coefficient and increasing fin thermal conductivity. In addition, shorter fins have higher fin efficiencies.

Hairpin sections can be combined in a variety of series or parallel arrangements to provide the required surface area while maintaining pressure drop limitations. Sections installed in series are normally mounted one on top of the other. Sections can also be connected in series/parallel (unbalanced) arrangements which are obtained using a combination of side-by-side and stacked mountings.

DOUBLE PIPE UNITS

Double pipe sections contain a single inner pipe or tube inside a pipe shell. Commercially available single tube sections have shells ranging from 2 through 6 in. pipe sizes (50 to 150 mm). The inner tube, which may be bare or longitudinally finned, is available with outside diameters of 1/2 to 4-1/2 in. (12 to 114 mm).

The fins, 12 to 72 per tube, are 1/2 to 1 in. high (12 to 25 mm), and 35 to 50 mils thick (0.9 to 1.3 mm). For change of phase services, the fins frequently contain holes to allow for fluid redistribution along the length of the tube.

Double Pipe sections can be economically justified if the equivalent shell and tube surface area required is less than approximately 400 ft² (40 m²). However, this criteria is not firm since the relative economics are a function of the service, materials, and installation costs.



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EQUIPMENT TYPES AND APPLICATIONS (Cont)

MULTITUBE UNITS

Multitube hairpin sections contain from 7 to 750 tubes, bare or longitudinally finned. Section shells range from 4 through 30 in. (200 to 760 mm) pipe or shell sizes. The inner tubes are available with outside diameters of 5/8 in. to 1-1/4 in. (16 to 37 mm). The fins, 12 to 20 per tube, are nominally 1/4 in. high (6 mm) and 35 mils thick (0.9 mm).

The surface area available in multitubes varies from approximately 40 ft² (3.75 m²) to 7000 ft² (650 m²). The larger hairpins can economically compete with TEMA type shell-and-tube heat exchangers when multiple shells in series are required due to a temperature cross.

DESIGN CONSIDERATIONS

Considerations like fluid placement, fouling factors, minimum velocities are the same as shell-and-tube heat exchangers. Therefore recommendations in [Sections IX-B](#) and [IX-C](#) should be followed. If the shell-side heat transfer coefficient is small compared to the tubeside, finned tubes should be considered. These exchangers are also available with segmental baffles like a shell-and-tube. To rate exchangers with baffles, refer to [Section IX-D](#).

CALCULATION PROCEDURE

The calculation procedure is based on single phase flow in both the tubes and the shell. If the flow on either side is changing phase (vaporization or condensation), follow the tube side calculation procedure in the appropriate subsection ([Section IX-E](#) or [IX-F](#)) to evaluate the heat transfer coefficient and pressure drop. When the change of phase stream is in the shell, use the hydraulic diameters.

The procedure should be used for rating existing equipment and checking vendor calculations. For new designs, it is common practice to supply the process data to the vendor and ask them to provide a design.

Geometry parameters of some commonly available sections are given in [Tables 1, 2, and 3](#). This information was provided by Brown Fintube Co. Geometry parameters for sections not listed can be calculated using [Table 4](#), and the vendors listed below may have other standard sizes.

VENDORS

The following vendors (all in the USA) may be contacted for additional information and quotations. A Specification Sheet is available in [GP 6-2-1](#).

1. Brown Fintube
Houston, Texas
(713) 466-3535
2. Alco Products
Wichita Falls, Texas
(940) 723-6366
3. R. W. Holland
Tulsa, Oklahoma
(918) 664-7822



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NOMENCLATURE

A	=	Total exchanger area, ft ² (m ²)
A_i	=	Inside surface area per unit tube length, ft ² /ft (m ² /m)
A_o	=	Outside surface area per unit tube length, ft ² /ft (m ² /m)
A_r	=	Required surface area, ft ² (m ²)
A_s	=	Surface area of one section, ft ² /f (m ² /m)
A_A	=	Annular flow area, ft ² (m ²)
A_F	=	Finned surface area per unit tube length, ft ² /ft (m ² /m)
C_p	=	Fluid specific heat, Btu/lb-°F (kJ/kg-°C)
d_i	=	Inside diameter of inner tube, in. (mm)
d_o	=	Outside diameter of inner tube, in. (mm)
d_{sni}	=	Inside diameter of shell inlet nozzle
d_{sno}	=	Inside diameter of shell outlet nozzle
d_2	=	Inside diameter of shell (or outer pipe), in. (mm)
D_{hh}	=	Hydraulic diameter for heat transfer calculations, in. (mm)
D_{hp}	=	Hydraulic diameter for pressure drop calculations, in. (mm)
h_i	=	Inside film coefficient, based on inside area, Btu/hr-ft ² -°F (W/m ² -°C)
h_o	=	Annular film coefficient, Btu/hr-ft ² -°F (W/m ² -°C)
H_f	=	Fin height, in.
k	=	Fluid thermal conductivity, Btu/hr-ft-°F (W/m-°C)
k_f	=	Thermal conductivity of fin material, Btu/hr-ft-°F (W/m-°C)
k_w	=	Thermal conductivity of tube wall, Btu/hr-ft-°F (W/m-°C)
L	=	Straight tube length, ft (m)
LMTD	=	Log Mean temperature difference, °F (°C)
N_f	=	Number of fins per tube
N_s	=	Number of sections in series
N_T	=	Number of tubes per section
Pr	=	Prandtl Number, (2.42 μ Cp/k or 1000 μ C _p /k)
ΔP_{ta}	=	Total annular pressure drop, psi (kPa)
ΔP_{tt}	=	Total tube side pressure drop, psi (kPa)
ΔP_f	=	Pressure drop due to friction, psi (kPa)
ΔP_n	=	Pressure drop in the nozzles, psi (kPa)
ΔP_e	=	Pressure drop due to expansion, contraction, entrance, psi (kPa)



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NOMENCLATURE (Cont)

Q	=	Rate of heat transfer (Heat Duty), Btu/hr (W)
r_f	=	Inside fouling resistance based on inside surface area, hr-ft ² -°F/Btu (m ² -°C/W)
r_w	=	Tube wall resistance, hr-ft ² -°F/Btu (m ² -°C/W)
R_f	=	Annular fouling resistance, hr-ft ² -°F/Btu (m ² -°C/W)
R_{io}	=	Inside film resistance corrected to outside area, hr-ft ² -°F/Btu (m ² -°C/W)
R_o	=	Annular film resistance, hr-ft ² -°F/Btu (m ² -°C/W)
R_t	=	Total resistance to heat transfer, hr-ft ² -°F/Btu (m ² -°C/W)
Re	=	Reynolds number (dimensionless)
t_i	=	Inlet temperature of tubeside fluid, °F (°C)
t_o	=	Outlet temperature of tubeside fluid, °F (°C)
T_f	=	Fin thickness, in. (mm)
T_i	=	Inlet temperature of annulus fluid, °F (°C)
T_o	=	Outlet temperature of annulus fluid, °F (°C)
U_o	=	Overall heat transfer coefficient, Btu/hr-ft ² -°F (m ² -°C/W)
V	=	Velocity, ft/sec (m/s)
W	=	Mass flow rate, lb/hr (kg/s)
X	=	Fin efficiency factor
ρ	=	Fluid density, lb/ft ³ (kg/m ³)
η	=	Fin efficiency
η'	=	Surface efficiency
μ	=	Fluid viscosity, cP (Pa•s)

Subscripts

a	=	annulus
t	=	tube
w	=	wall
av	=	average



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TABLE 1A
DATA FOR BARE AND FINNED DOUBLE PIPE SECTIONS (CUSTOMARY)

NO.	SHELL		TUBE				FINS		AREAS				
	NOMINAL SIZE (in.)	ID d ₂ (in.)	NOM. OD (in.)	ACTUAL OD, d _o (in.)	THICK. (in.)	ID d _i (in.)	NO. N _f	HGT. H _f (in.)	ANNULUS A _A (ft ²)	FINS A _F (ft ²)	TOTAL A _O (ft ²)	RATIO A _F /A _O	RATIO A _O /A _i
1	2.0	2.067	1.0	1.000	0.109	0.782	0	0.50	0.018	0.000	0.262	0.00	1.28
2	2.0	2.067	1.0	1.000	0.109	0.782	16	0.50	0.016	1.333	1.595	0.84	7.79
3	2.0	2.067	1.0	1.000	0.109	0.782	24	0.50	0.015	2.000	2.262	0.88	11.05
4	3.0	3.068	1.5	1.900	0.145	1.610	0	0.50	0.032	0.000	0.497	0.00	1.18
5	3.0	3.068	1.5	1.900	0.145	1.610	16	0.50	0.030	1.333	1.831	0.73	4.35
6	3.0	3.068	1.5	1.900	0.145	1.610	28	0.50	0.028	2.333	2.831	0.82	6.72
7	3.0	3.068	1.5	1.900	0.145	1.610	36	0.50	0.027	3.000	3.497	0.86	8.30
8	4.0	4.026	1.5	1.900	0.145	1.610	0	1.00	0.069	0.000	0.497	0.00	1.18
9	4.0	4.026	1.5	1.900	0.145	1.610	16	1.00	0.065	2.667	3.164	0.84	7.51
10	4.0	4.026	1.5	1.900	0.145	1.610	28	1.00	0.062	4.667	5.164	0.90	12.26
11	4.0	4.026	1.5	1.900	0.145	1.610	36	1.00	0.060	6.000	6.497	0.92	15.42
12	4.0	4.026	2.0	2.375	0.154	2.067	0	0.75	0.058	0.000	0.621	0.00	1.15
13	4.0	4.026	2.0	2.375	0.154	2.067	16	0.75	0.055	2.000	2.621	0.76	4.85
14	4.0	4.026	2.0	2.375	0.154	2.067	28	0.75	0.053	3.500	4.121	0.85	7.62
15	4.0	4.026	2.0	2.375	0.154	2.067	40	0.75	0.050	5.000	5.621	0.89	10.39
16	4.0	4.026	2.5	2.875	0.203	2.469	0	0.50	0.043	0.000	0.752	0.00	1.16
17	4.0	4.026	2.5	2.875	0.203	2.469	16	0.50	0.041	1.333	2.086	0.64	3.23
18	4.0	4.026	2.5	2.875	0.203	2.469	32	0.50	0.039	2.667	3.419	0.78	5.29
19	4.0	4.026	2.5	2.875	0.203	2.469	48	0.50	0.037	4.000	4.752	0.84	7.36
20	5.0	5.047	3.0	3.500	0.216	3.068	0	0.688	0.072	0.000	0.916	0.00	1.14
21	5.0	5.047	3.0	3.500	0.216	3.068	28	0.688	0.067	3.208	4.124	0.78	5.14
22	5.0	5.047	3.0	3.500	0.216	3.068	40	0.688	0.065	4.583	5.499	0.83	6.85
23	5.0	5.047	3.0	3.500	0.216	3.068	56	0.688	0.063	6.417	7.333	0.88	9.13
24	6.0	6.065	4.0	4.500	0.237	4.026	0	0.688	0.090	0.000	1.178	0.00	1.12
25	6.0	6.065	4.0	4.500	0.237	4.026	36	0.688	0.084	4.125	5.303	0.78	5.03
26	6.0	6.065	4.0	4.500	0.237	4.026	56	0.688	0.081	6.417	7.594	0.84	7.21
27	6.0	6.065	4.0	4.500	0.237	4.026	72	0.688	0.078	8.250	9.428	0.88	8.95

Notes:

1. Total surface area (A) for a straight section: $A_s = A_o (L)$
2. Total surface area (A) for a hairpin section: $A_s = A_o (2L)$
3. **GP 6-2-1** requires a minimum Schedule 40 shell for carbon and low alloy steel, and Schedule 10 for high alloy and non-ferrous material.

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TABLE 1B
DATA FOR BARE AND FINNED DOUBLE PIPE SECTIONS (METRIC)

NO.	SHELL		TUBE				FINS		AREAS				
	NOMINAL SIZE (mm)	ID d ₂ (mm)	NOM. OD (mm)	ACTUAL OD, d _o (mm)	THICK. (mm)	ID d _i (mm)	NO. N _f	HGT. H _f (mm)	ANNULUS A _A (m ²)	FINS A _F (m ² /m)	TOTAL A _o (m ² /m)	RATIO A _F /A _o	RATIO A _o /A _i
1	50.8	52.5	25.4	25.4	2.769	19.86	0	12.70	0.0017	0.000	0.080	0.00	1.28
2	50.8	52.5	25.4	25.4	2.769	19.86	16	12.70	0.0015	0.406	0.486	0.84	7.79
3	50.8	52.5	25.4	25.4	2.769	19.86	24	12.70	0.0014	0.610	0.689	0.88	11.05
4	76.2	77.9	38.1	48.3	3.683	40.89	0	12.70	0.0029	0.000	0.152	0.00	1.18
5	76.2	77.9	38.1	48.3	3.683	40.89	16	12.70	0.0028	0.406	0.558	0.73	4.35
6	76.2	77.9	38.1	48.3	3.683	40.89	28	12.70	0.0026	0.711	0.863	0.82	6.72
7	76.2	77.9	38.1	48.3	3.683	40.89	36	12.70	0.0025	0.914	1.066	0.86	8.30
8	101.6	102.3	38.1	48.3	3.683	40.89	0	25.40	0.0064	0.000	0.152	0.00	1.18
9	101.6	102.3	38.1	48.3	3.683	40.89	16	25.40	0.0060	0.813	0.964	0.84	7.51
10	101.6	102.3	38.1	48.3	3.683	40.89	28	25.40	0.0057	1.422	1.574	0.90	12.26
11	101.6	102.3	38.1	48.3	3.683	40.89	36	25.40	0.0056	1.829	1.980	0.92	15.42
12	101.6	102.3	50.8	60.3	3.912	52.50	0	19.05	0.0054	0.000	0.189	0.00	1.15
13	101.6	102.3	50.8	60.3	3.912	52.50	16	19.05	0.0051	0.610	0.799	0.76	4.85
14	101.6	102.3	50.8	60.3	3.912	52.50	28	19.05	0.0049	1.067	1.256	0.85	7.62
15	101.6	102.3	50.8	60.3	3.912	52.50	40	19.05	0.0047	1.524	1.713	0.89	10.39
16	101.6	102.3	63.5	73.0	5.156	62.71	0	12.70	0.0040	0.000	0.229	0.00	1.16
17	101.6	102.3	63.5	73.0	5.156	62.71	16	12.70	0.0038	0.406	0.636	0.64	3.23
18	101.6	102.3	63.5	73.0	5.156	62.71	32	12.70	0.0037	0.813	1.042	0.78	5.29
19	101.6	102.3	63.5	73.0	5.156	62.71	48	12.70	0.0035	1.219	1.448	0.84	7.36
20	127.0	128.2	76.2	88.9	5.486	77.93	0	17.46	0.0067	0.000	0.279	0.00	1.14
21	127.0	128.2	76.2	88.9	5.486	77.93	28	17.46	0.0063	0.978	1.257	0.78	5.14
22	127.0	128.2	76.2	88.9	5.486	77.93	40	17.46	0.0061	1.397	1.676	0.83	6.85
23	127.0	128.2	76.2	88.9	5.486	77.93	56	17.46	0.0058	1.956	2.235	0.88	9.13
24	152.4	154.1	101.6	114.3	6.020	102.26	0	17.46	0.0084	0.000	0.359	0.00	1.12
25	152.4	154.1	101.6	114.3	6.020	102.26	36	17.46	0.0078	1.257	1.616	0.78	5.03
26	152.4	154.1	101.6	114.3	6.020	102.26	56	17.46	0.0075	1.956	2.315	0.84	7.21
27	152.4	154.1	101.6	114.3	6.020	102.26	72	17.46	0.0073	2.515	2.874	0.88	8.95

Notes:

1. Total surface area (A) for a straight section: $A_s = A_o (L)$
2. Total surface area (A) for a hairpin section: $A_s = A_o (2L)$
3. **GP 6-2-1** requires a minimum Schedule 40 shell for carbon and low alloy steel, and Schedule 10 for high alloy and non-ferrous material.

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TABLE 2A
DATA FOR BARE MULTITUBE SECTIONS (3 - 16 IN.), CUSTOMARY

NO.	SHELL		TUBE				AREAS			
	NOMINAL SIZE (in.)	ID d ₂ (in.)	OD d _o (in.)	THICK. (in.)	NO. N _T	ID d _i (in.)	ANNULUS A _A (ft ²)	TOTAL A _o N _T (ft ² /ft)	U BEND (ft ²)	RATIO A _o /A _i
28	3.0	3.068	0.750	0.109	7	0.532	4.30	1.37	1.09	1.41
29	4.0	4.026	0.750	0.109	10	0.532	8.31	1.96	1.93	1.41
30	4.0	4.026	1.000	0.109	7	0.782	7.23	1.83	1.80	1.28
31	5.0	5.047	0.750	0.109	19	0.532	11.61	3.73	4.39	1.41
32	5.0	5.047	1.000	0.109	8	0.782	13.72	2.09	2.47	1.28
33	6.0	6.065	0.750	0.109	24	0.532	18.28	4.71	7.40	1.41
34	6.0	6.065	1.000	0.109	13	0.782	18.67	3.40	5.35	1.28
35	8.0	7.981	0.750	0.109	48	0.532	28.81	9.42	16.50	1.41
36	8.0	7.981	1.000	0.109	24	0.782	31.16	6.28	11.00	1.28
37	10.0	10.020	0.750	0.109	85	0.532	41.28	16.68	38.22	1.41
38	10.0	10.020	1.000	0.109	42	0.782	45.84	10.99	25.19	1.28
39	12.0	11.938	0.750	0.109	121	0.532	58.45	23.75	62.18	1.41
40	12.0	11.938	1.000	0.109	64	0.782	61.63	16.75	43.87	1.28
41	16.0	15.000	0.750	0.109	199	0.532	88.75	39.05	132.95	1.41
42	16.0	15.000	1.000	0.109	109	0.782	91.06	28.52	97.12	1.28
43	4.0	4.026	0.750	0.109	9	0.532	8.75	1.77	1.11	1.41
44	5.0	5.047	0.750	0.109	12	0.532	14.70	2.36	2.78	1.41
45	5.0	5.047	1.000	0.109	9	0.782	12.93	2.36	2.78	1.28
46	6.0	6.065	0.750	0.109	21	0.532	19.60	4.12	6.48	1.41
47	6.0	6.065	1.000	0.109	12	0.782	19.46	3.14	4.93	1.28
48	8.0	7.981	0.750	0.109	37	0.532	33.66	7.26	12.72	1.41
49	8.0	7.981	1.000	0.109	24	0.782	31.16	6.28	11.00	1.28
50	10.0	10.020	0.750	0.109	61	0.532	51.88	11.97	27.43	1.41
51	10.0	10.020	1.000	0.109	37	0.782	49.77	9.68	22.19	1.28
52	12.0	11.938	0.750	0.109	89	0.532	72.58	17.47	45.74	1.41
53	12.0	11.938	1.000	0.109	57	0.782	67.13	14.92	39.07	1.28
54	16.0	15.000	0.750	0.109	148	0.532	111.27	29.05	98.88	1.41
55	16.0	15.000	1.000	0.109	97	0.782	100.48	25.38	86.43	1.28

Notes:

- Section No. 28-42 are for triangular layout; 43-55 are for rotated square layout.
- Total surface area (A) for a straight section: $A_s = A_o N_T (L)$
- Total surface area (A) for a hairpin section: $A_s = A_o N_T (2L) + U \text{ bend area}$
- GP 6-2-1** requires a minimum Schedule 40 shell for carbon and low alloy steel, and Schedule 10 for high alloy and non-ferrous material.

