Heat transfer from oriented heat exchange areas

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Abstract. This paper deals with the transfer of heat-driven heat transfer surface area in relation to the construction of the criterion equation for “n” horizontal pipe one above another. On the bases of theoretical models have been developed for calculating the thermal performance of natural convection by Churilla and Morgan, for various pipe diameters and temperatures. These models were compared with models created in CFD-Fluent Ansys the same boundary conditions. The aim of the analyse of heat and fluxional pipe fields „n“ pipes one above another at natural convection is the creation of criterion equation on the basis of which the heat output of heat transfer from pipe oriented areas one above another with given spacing could be quantified. At presence a sum of criterion equations exists for simple geometrical shapes of individual oriented geometrical areas but the criterion equation which would consider interaction of fluxional field generated by free convection from multiple oriented areas is not mentioned in standardly accessible technical literature and other magazine publications.

1 Introduction

Creation of criterion equation for calculation of heat output is signified for quantification of heat outputs calculations of geometrically more complicated heat transfer areas in engineering praxis and furthermore for optimization of processes such as schemes of pipe heat bodies and many other applications in technical praxis that are related to heat transfer by free convection. The process of finding a new criterion equation for above mentioned geometries was carried out on the basis of numerical experiment by simulation of heat transfer for various thermo-kinetic and geometrical parameters of pipe alignment one above another. Some simulations were verified by measuring of output of real pipe system in specialized thermostatic chamber. Used numeric model of CFD method was validated by this way.

On the basis of this comparison where equalities will be gained in calculated and modelled results, models will be created in the programme Ansys-Fluent for „n“ horizontal pipes one above another.

Data from this program and famous criterion equation for one pipe will be used to create criterion relation to calculate Nusselt number for „n“ pipes one above another. A criterion relation for calculating Nusselt number according to Morgan [1] will be used on the basis of analyses of heat transfer of one horizontal pipe.

2 Materials and Methods

Modelling of output parameters of one horizontal pipe at natural convection was carried out both in programme Ansys 13 – Workbench as well as by using known criterion equations of similarity theory for one horizontal pipe. Numeric modelling was carried out with the aim to verify both methods of calculating output parameters at natural convection of one horizontal pipe. Mentioned verification enabled us relevant using of programme Ansys 13 – Workbench to gain wide database of heat outputs of explored pipe system by various thermo-kinetic parameters and heat transfer area geometry and as well as by creating of criterion equation for natural convection of „n“ pipes one above another.

Figure 1. The basic scheme of calculation

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To compare mathematical model created on the basis of criterion equations and by a calculation in the programme Ansys 13 – Workbench, comparisons of calculated output parameters of natural convection of horizontal pipe were created. In both examples more simulations were carried out whose results are given in following tables or graphs with simulated pipes with mostly used diameter 15-66 mm, at pipe temperatures 30°C -105°C and at a surrounding temperature 20°C.

The basic procedure scheme analysis of heat transport from horizontal pipe by natural convection is shown in Figure 1. To visualize the temperature field and also for the calculation of performance characteristics was necessary to create the geometry of heat transfer from horizontal pipe by natural convection (the application storage tubes in unbounded space was used) in the first step.

For a long horizontal cylinder (pipe, heat pipe exchanger...) as a characteristic diameter is the outer diameter of pipe. According to Morgan [1] is the simple relation for determine the mean Nusselt number:

$$\overline{Nu}_d = \frac{\overline{\alpha}d}{\lambda} = C Ra_d^n \quad (1)$$

where the multiple article C and exponent n are depended on Rayleigh criteria number in table 1.

Table 1. The basic scheme of calculation

Ra_d	C	n
10^{-10} - 10^{-2}	0,675	0,058
10^{-2} - 10^2	1,02	0,148
10^2 - 10^4	0,85	0,188
10^4 - 10^7	0,48	0,25
10^7 - 10^{12}	0,125	0,333

Figure 2. The basic scheme of calculation

Churchill suggests a relation for all range of Rayleigh number (2):

$$Ra_d = \frac{g\beta(T_s - T_\infty)d^3}{\nu\alpha} \quad (2)$$

$$Nu_d = \left\{ 0,60 + \frac{0,387 Ra_d^{1/6}}{[1 + (0,559/Pr)^{9/16}]^{8/27}} \right\}^2 \quad (3)$$

3 Results

Modelling of heat transfer from horizontal pipe in the programme Ansys 13 – Workbench was carried out in the system of analyses Fluid Flow (Fluent) using the finite volume method. To simplify calculations and in consideration of pipe geometry the 2-D model could be used to calculate heat transfer from horizontal pipe with given parameter, which was a diameter of horizontal pipe. Following boundary conditions of calculation were entered in the program Fluent:

- laminar model of streaming (results from calculation of Rayleigh number, for which is the critical value $Ra_{krit} = 10^9$ for laminar streaming)
- pipe's wall temperature – entered as parameter
- bounding control area for analysing natural convection defined as „pressure outlet“ with given temperature 20°C which is $T_\infty = 20^\circ\text{C}$
- acceleration of gravity $9,80665 \text{ m.s}^{-2}$
- Boussinesq model of calculating air density, suitable for natural convection (according to Fluent publication)
- under relaxation factors except for energy and pressure decreased on half (according to Fluent publication)

Figure 3. Mathematical mesh of horizontal pipe and surrounding

After the entering the boundary conditions and configurations parameters for parametric analysis was activate the calculation. Programme Ansys Parameters

was started after the calculation was converged. Eighteen diameters of the horizontal pipes were set (diameters from 16 mm to 66 mm).

Figure 4. Temperature fields of horizontal pipes with the diameter 15mm, 27mm, 45mm, 66mm at wall temperature 30°C and at surrounding temperature 20°C

Figure 5. Temperature fields of horizontal pipes with the diameter 15mm, 27mm, 45mm, 66mm at wall temperature 75°C and at surrounding temperature 20°C

Temperature fields at natural convection from horizontal pipe are visualized in the Figures 4-6, where pipes with the diameter 15 mm, 27 mm, 45 mm and 66 mm are shown at temperatures 30°C, 45°C, 60°C, 75°C, 90°C and 105°C and at a surrounding temperature 20°C. It is evident from these pictures that the diameter of the pipe and its wall temperature highly influences the size and shape of the marginal layer, the geometry of the heat flow behind the pipe and the reach of heated air above the pipe. The character of streaming by these wall temperatures and diameters is laminar.

Figure 6. Temperature fields of horizontal pipes with the diameter 15mm, 27mm, 45mm, 66mm at wall temperature 105°C and at surrounding temperature 20°C

As the diameter as well as the temperature, as was found out by previous simulations, have a very important influence on the character of the streaming and finally also on transferred output at natural convection two nondimensional parameters were selected S/D and T_{∞}/T_s , where „ S “ is the pipe spacing, „ D “ is the pipe diameter, „ T_{∞} “ is the surrounding temperature and T_s is the pipe's wall temperature. Heat outputs of horizontal pipe at a wall temperature 30°C, 45°C, 60°C, 75°C, 90°C and 105°C are shown in the table 2.

Table 2. Heat outputs of horizontal pipe at a surrounding temperature 20°C and at pipe's wall temperatures 30-105°C

Diameters	30°C Q [W]	45°C Q [W]	60°C Q [W]	75°C Q [W]	90°C Q [W]	105°C Q [W]
15	3,14	9,75	17,43	25,64	33,25	43,74
18	3,56	11,00	19,63	29,11	39,25	49,93
21	3,97	12,32	22,07	32,80	44,33	56,53
24	4,33	13,49	24,18	35,96	48,61	62,05
27	4,73	14,72	26,39	39,27	52,82	67,35
30	5,10	15,97	28,71	42,76	57,87	73,88
33	5,42	16,88	30,28	45,03	60,81	77,49
36	5,82	18,28	32,95	49,20	66,69	85,26
39	6,18	19,42	34,96	52,20	70,77	90,42
42	6,47	20,28	36,54	54,36	73,65	94,12
45	6,81	21,43	38,67	57,79	78,45	100,37
48	7,23	22,88	41,40	62,00	84,26	107,91
51	7,52	23,82	43,12	64,58	87,73	112,33
54	7,96	25,41	46,23	69,44	94,32	121,02
57	8,18	25,98	47,19	70,72	96,24	123,39
60	8,48	26,88	48,70	72,84	98,95	126,68
63	8,86	28,25	51,36	77,11	104,95	134,54
66	9,07	28,92	52,51	78,83	107,31	137,60

Modelling of heat transport from horizontal pipes at natural convection was carried out also on the basis of criterion equations of similarity theory (relation 1-3).

Table 3 Heat outputs of horizontal pipe at a surrounding temperature 20°C and at pipe's wall temperatures 30-105°C according to Churchill

Calculation of Nu according to Churchill relation						
Diameter [mm]	30°C Q [W]	45°C Q [W]	60°C Q [W]	75°C Q [W]	90°C Q [W]	105°C Q [W]
15	2,75	8,55	15,41	23,05	31,32	40,15
18	3,11	9,74	17,61	26,37	35,87	46,02
21	3,47	10,91	19,75	29,62	40,33	51,78
24	3,82	12,05	21,86	32,82	44,72	57,44
27	4,16	13,18	23,94	35,97	49,04	63,03
30	4,5	14,29	25,99	39,08	53,32	68,55
33	4,84	15,39	28,02	42,16	57,55	74,02
36	5,17	16,47	30,03	45,21	61,74	79,44
39	5,49	17,55	32,02	48,24	65,9	84,82
42	5,82	18,62	34	51,25	70,04	90,16
45	6,14	19,68	35,96	54,24	74,14	95,47
48	6,46	20,74	37,92	57,2	78,23	100,75
51	6,81	22,03	40,59	61,68	84,92	110,1
54	7,09	22,83	41,79	63,1	86,33	111,23
57	7,4	23,87	43,71	66,02	90,35	116,43
60	7,72	24,9	45,63	68,94	94,36	121,61
63	8,03	25,93	47,54	71,84	98,35	126,78
66	8,34	26,95	49,44	74,73	102,33	131,92

This modelling was carried out by same boundary conditions as by modelling in the programme Ansys because of comparing used calculation methods. This means that calculations of outputs were carried out for horizontal pipe diameters from 15mm to 66mm at a wall temperature 30°C, 45°C, 60°C, 75°C, 90°C, 105°C and at a surrounding temperature 20°C. Heat outputs of horizontal pipe at natural convection calculated with the help of Nuselt number according to Morgan relation [1] as well as according to Churchill relation [2] (relation 1-3). Using two different criterion relations for calculating heat output of horizontal pipe at natural convection was carried out to compare these two relations with calculation in the programme Ansys – Fluent and consequently to choose suitable calculation criterion relation to define the Nuselt number.

Table 4 Heat outputs of horizontal pipe at a surrounding temperature 20°C and at pipe's wall temperatures 30-105°C according to Morgan

Calculation of Nu according to Churchill relation						
Diameter [mm]	30°C Q [W]	45°C Q [W]	60°C Q [W]	75°C Q [W]	90°C Q [W]	105°C Q [W]
15	2,75	8,55	15,41	23,05	31,32	40,15
18	3,11	9,74	17,61	26,37	35,87	46,02
21	3,47	10,91	19,75	29,62	40,33	51,78
24	3,82	12,05	21,86	32,82	44,72	57,44
27	4,16	13,18	23,94	35,97	49,04	63,03
30	4,5	14,29	25,99	39,08	53,32	68,55
33	4,84	15,39	28,02	42,16	57,55	74,02
36	5,17	16,47	30,03	45,21	61,74	79,44
39	5,49	17,55	32,02	48,24	65,9	84,82
42	5,82	18,62	34	51,25	70,04	90,16
45	6,14	19,68	35,96	54,24	74,14	95,47
48	6,46	20,74	37,92	57,2	78,23	100,75
51	6,81	22,03	40,59	61,68	84,92	110,1
54	7,09	22,83	41,79	63,1	86,33	111,23
57	7,4	23,87	43,71	66,02	90,35	116,43
60	7,72	24,9	45,63	68,94	94,36	121,61
63	8,03	25,93	47,54	71,84	98,35	126,78
66	8,34	26,95	49,44	74,73	102,33	131,92

Graph 1. Heat output of horizontal pipe at natural convection at the temperature of pipe's wall 30°C and at the surrounding temperature 20°C

Graph 2. Heat output of horizontal pipe at natural convection at the temperature of pipe's wall 45°C and at the surrounding temperature 20°C

Graph 3. Heat output of horizontal pipe at natural convection at the temperature of pipe's wall 90°C and at the surrounding temperature 20°C

Graph 4. Heat output of horizontal pipe at natural convection at the temperature of pipe's wall 105°C and at the surrounding temperature 20°C

Relations of calculated heat output of horizontal pipe at natural convection are shown in following graphs (graph 1 to 4). In graphs are shown calculations with the help of programme Ansys-Fluent as well as on the basis of criterion equations.

Summary

Two already mentioned calculation relations of calculating Nusselt number were used to calculate heat output on the basis of criterion equations. From these graphs is evident that to calculate heat output of horizontal pipe at natural convection from criterion equations the relation according to Morgan [1] corresponds with the calculation in the programme Ansys – Fluent better than the calculation of heat output using criterion equation according to Churchill. This closeness of output processes is evident in whole simulated range, it means by horizontal pipes with diameters 15 mm to 66 mm at a wall temperature 30°C, 45°C, 60°C, 75°C, 90°C, 105°C and at surrounding temperature 20°C. As it is seen from these graphs and tables the differences of calculated heat outputs according to these two criterion relations are minimal, which can be caused by the fact that Churchill relation is given for whole range of Rayleigh number $10^{-5} < \text{Rad} < 10^{12}$ in contrast to Morgan relation which defines multiple relations in various ranges Rad. In the near future we want to create a criterion equation for „n“ horizontal pipes one above another. On the basis of this comparison where equalities will be gained in calculated and modelled results, models will be created in the programme Ansys-Fluent for „n“ horizontal pipes one above another.

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