Institute of Fluid Mechanics
and Heat Transfer
Vienna University of Technology
A-1040 Vienna, Austria

Heat Transfer Analysis of Reciprocating Compressors

R. Aigner, L. Savic, H. Steinrück[1]

1 Introduction

The purpose of this investigation is to perform a heat transfer analysis of the compression chamber of a reciprocating compressor.

The essential part of the heat supply to the compressor is due to the temperature rise of the compressed gas during compression. Thus the main contribution to the heat balance of a reciprocating compressor is the heat transfer from the gas to the mechanical structure, e.g. the cylinder, the piston, the cylinder cap and piston rod to name the most prominent surfaces of the compression chamber. Of course there are some empirical estimates of the heat transfer from the gas to the compressor. These formulas are naturally very crude since it cannot be expected to capture the heat transfer process within the cylinder which depends on complex flow processes by a simple formula.

The other extreme of describing the heat transfer would be the full numerical simulation including the heat transfer analysis of the mechanical structure, the exchange of heat with the environment and the flow and heat transfer processes in the compressor as well. Such a simulation is nowadays possible and state of the art. However, such an approach is for most application too expensive since the license and manpower costs to run a simulation tool efficiently are too high. Therefore an approach combining both extremes will be pursuit.

The goal is to derive simple correlations for the heat transfer. The method to reach the goal is to use well proven commercial CFD tools, perform a sufficient number of numerical experiments and finally extract correlation formulas.

2 The method

The general procedure has the following main steps

Step 1 Determine the the heat fluxes and heat transfer coefficients from the gas to the compressor for a sufficient number of cases by numerical simulations.

Step 2 Reconstruct the the heat fluxes through the individual faces by an ansatz which depends only on few dimensionless parameters.

Step 3 Find correlation between these dimensionless parameters for the heat flux reconstruction and the process parameters.

2.1 Assumptions for the simulation

We make the following assumptions

(A1) The flow in the cylinder is almost inviscid. In the following we will base the Reynolds number

$$\mathrm{Re} = \frac{\rho_{\mathrm{in}} u_p d_p}{\mu}$$

[1]E-mail: herbert.steinrueck@tuwien.ac.at
Address: Vienna University of Technology, Institute of Fluid Mechanics and Heat Transfer, Resselgasse 3, 1040 Vienna, Austria

on a reference value for the piston velocity $u_p = h\,f$, the cylinder diameter d_p, the gas density ρ_{in} and dynamic viscosity μ of the gas at inflow conditions. Here h denotes the stroke and f the frequency (number of cycles per second) of the piston motion.

For realistic compressor data the Reynolds number turns out to be of the order 10^4 to 10^5. Thus we expect a turbulent flow in the cylinder.

(A2) In a turbulent flow the heat transfer from the fluid (gas) to the surrounding structure (cylinder) is determined by the local flow properties along the wall. Thus we assume that the local heat transfer coefficient is a local flow property.

(A3) To determine a heat transfer coefficient a characteristic temperature has to be identified. Although in general the fluid temperature in the interior will not be uniform we relate the heat transfer coefficient to the difference between the wall temperature and the mean fluid temperature. The mean gas temperature is defined by averaging the internal energy over the compression chamber.

This approach is justified if the spatial variation of the gas temperature inside the cylinder turns out to be small. If this assumption really holds will be discussed later.

(A4) We assume that the local heat transfer coefficient is independent from the actual wall temperature. This is justified since the heat transfer coefficient in a turbulent flow is a flow property and does not dependent on the local temperature.

As a consequence we can extract the heat transfer coefficients from a simulation with constant wall temperature.

(A5) The interaction of the valves with the flow field is simplified. For the out flow valve we assume that it closed until the pressure in the cylinder exceeds the opening pressure given by the pressure in the pressure pipe plus taking the springing of the valve plate into account. When the valve has opened completely it is kept open until the piston reaches the dead point.

Thus for the sake of simplicity the delicate interaction of the valve with the internal waves in the compressor is neglected.

2.2 Reconstruction

The basic idea of the reconstruction is to relate via the dimensionless Stanton number St the local heat flux density $\dot{q}$ to a reference enthalpy flux density $\dot{h}_{\text{ref}}$.

$$\dot{q} = \text{St}\,\dot{h}_{\text{ref}} = \text{St}\,\rho_{\text{ref}} c_p \Delta T u_{\text{ref}}, \tag{1}$$

where ΔT is a characteristic temperature difference. In the following we have to discuss, how to choose reference values for the flow velocity, the mass density and the temperature difference. As usual we choose the sign of the heat flux to be negative, if the heat flux vector is pointing out of the compression chamber. In order to find relevant reference values for the flow velocity u_{ref} we have to understand the flow behavior.

Thus we distinguish three different phases during a working cycle:

2.2.1 Inflow

The gas enters through the suction valve We expect a jet of cold gas emanating at the suction valve and impinging onto the piston rod or surfaces adjacent to the suction valve.

We extract the reference velocity from the inlet mass flow $\dot{m}_{\text{in}}$ through the suction valve:

$$u_{\text{ref,in}} = \dot{m}_{\text{in}}/\rho_{\text{in}} A_{\text{cross}}(t) \tag{2}$$

where the $A_{\text{cross}}(t) = d_p\,z(t)$ is the cross section of the compression chamber along the piston rod and $z(t)$ is the distance of the piston from the cylinder head. The density is taken from the values of the thermodynamic state of the gas at inflow.

The heat transfer will be influenced only after some retardation time t_0 since it takes some time that the cold gas impinges at the surfaces of the compression chamber. Thus we write the associated heat flux through a surface of area $A(t)$ of the compression chamber as a function of the time t as

$$\dot{Q}_{\text{in}}(t) = \text{St}_{\text{in}} c_p (T_w - T_{\text{in}}) \frac{A(t)}{A_{\text{cross}}(t)} \dot{m}_{\text{in}}(t - t_0) \tag{3}$$

We estimate t_0 as the time the inflow jet with velocity u_{injet} reaches the center of the cylinder

$$t_0 = \frac{d}{2u_{\text{injet}}} \tag{4}$$

The inflow velocity u_{injet} is estimated by

$$u_{\text{injet}} = \frac{\dot{m}_{\text{in}}}{\rho A_{\text{eff}}} \tag{5}$$

where A_{eff} is the effective flow cross section of the inflow path. It is the cross section A_{slot} of the opening between the cylinder and the valve pocket times an empirical factor f_{ret}, $A_{\text{eff}} = A_{\text{slot}} f_{\text{ret}}$ which has been set for 2.5 for when considering the piston, the cylinder had and the piston rod and $f_{\text{ret}} = 5.0$ for the cylinder barrel.

Using the crank angle $\varphi_0 = 2\pi f t_0$ instead of the time we express the retardation by the retardation angle φ_0

$$\varphi_0 = \pi \frac{f d \rho_{\text{in}} A_{\text{eff}}}{\bar{\dot{m}}_{\text{in}}} \tag{6}$$

To be precise we take the maximum value of the in-flowing mass flow during the period of time when the suction valve is open. Expressing the retardation crank angle ϕ_0 in degree we have

$$\varphi_0[^\circ] = 3 \frac{n\, d\, \rho_{\text{in}} A_{\text{eff}}}{\bar{\dot{m}}_{\text{in}}},$$

where n denotes the number of revolutions per minute.

The main surfaces of the compression chamber are the piston, cylinder cap, piston rod and the cylinder barrel. Their areas are

$$A_{\text{rod}} = \pi d_{\text{rod}} z(t), \quad A_{\text{pist}} = A_{\text{cap}} = \pi d_p^2/4, \quad A_{\text{barr}} = \pi d_p z(t). \tag{7}$$

2.2.2 Outflow

During outflow we expect that the flow is dominated by the outflow of the gas. Similar to the inflow phase we set

$$u_{\text{ref,out}} = \dot{m}_{\text{out}}/\rho_{\text{out}} A_{\text{cross}}(t) \tag{8}$$

The choice of a reference density is not of relevance since it does not appear in the formula for the heat flux density when expressing the heat flux density in terms of the mass flow.

Thus the local velocities will be proportional to the out going mass flow $|\dot{m}_{\text{out}}|$. Thus the heat transfer realted to the out going mass flow is

$$\dot{Q}_{\text{out}}(t) = \text{St}_{\text{out}} c_p \frac{A(t)}{A_{\text{cross}}(t)} |\dot{m}_{\text{out}}| (T_w - T_{\text{gas}}). \tag{9}$$

For the outflow no retardation is necessary since the information that the valve is open spreads with the velocity of sound which is considerable large than the actual flow velocity.

2.2.3 Compression

In the compression phase a natural reference velocity is the actual velocity of the piston $u_p(t)$. However, at the turning points of the piston motion it is zero but the heat flux density will not vanish. Thus as a second reference velocity we choose $u_\mathrm{m} = h \cdot f$ which is $\frac{2}{\pi}$ the average of the modulus of the piston speed. Thus we have

$$\dot{Q}_\mathrm{comp} = \left(\mathrm{St}_p \frac{u_p(t)}{u_m} + \mathrm{St}_m\right) \rho_\mathrm{isen}(t) u_m c_p \Delta T A(t) \tag{10}$$

As reference density we use the density $\rho_\mathrm{isen}(T)$ which results from an isentropic change of state from the inflow condition $(\rho_\mathrm{in}, T_\mathrm{in})$ to the actual gas temperature T in the compressor.

Let the iso-choric heat capacity c_v of the ideal gas depend linearly on the temperature

$$c_v(T) = c_{v,0} + c_{v,T} T \tag{11}$$

then the density ρ_isen is given by

$$\rho_\mathrm{isen}(T) = \rho_\mathrm{in} \left(\frac{T}{T_\mathrm{in}}\right)^{\frac{c_{v,0}}{R}} \exp\left(\frac{c_{v,T}}{c_{v,0}}(T - T_\mathrm{in})\right). \tag{12}$$

Note that difference between the isobaric heat capacity c_p and the iso-choric heat capacity c_v is the gas constant $R = c_p - c_v$.

Up to now we have estimated the specific enthalpy difference by $c_p(T_w - T_\mathrm{gas}$ assuming implicitly constant heat capacities. In case of a temperature dependent heat capacity we define an averaged heat capacity by using the the enthalpy difference is given by

$$h(T_w) - h/T_\mathrm{gas}) = \int_{T_w}^{T_\mathrm{gas}} c_p(T)\,\mathrm{d}T = \bar{c}_p \cdot (T_w - T_\mathrm{gas})$$

In case of linear dependence of the heat capacity of the temperature we have

$$\bar{c}_p = c_{p,0} + c_{v,T} \frac{T_w + T_\mathrm{gas}}{2} = c_p\left(\frac{T_w + T_\mathrm{gas}}{2}\right)$$

Note that $c_p - c_v = R$ and thus $c_p = c_{p,0} + c_{v,T} T$.

Summarizing the reconstructed heat flux $\dot{Q}_\mathrm{rec}(t)$ has the form

$$\begin{aligned} \dot{Q}_\mathrm{rec}(t) &= \mathrm{St}_\mathrm{in} \frac{A(t)}{A_\mathrm{cross}(t)} \dot{m}_\mathrm{in}(t - t_0) \bar{c}_p (T_w - T_\mathrm{gas}) \\ &+ \mathrm{St}_\mathrm{out} \frac{A(t)}{A_\mathrm{cross}(t)} |\dot{m}_\mathrm{out}| \bar{c}_p (T_w - T_\mathrm{gas}) \\ &\left(\mathrm{St}_p \frac{u_p(t)}{u_m} + \mathrm{St}_m\right) A(t) \rho_\mathrm{isen}(T_\mathrm{gas}) u_m \bar{c}_p (T_w - T_\mathrm{gas}) \end{aligned} \tag{13}$$

2.3 Heat transfer coefficient

Dividing the total heat-flux by the area of the surface under consideration and the temperature difference we obtain the spatially averaged heat transfer coefficient

$$\begin{aligned} \alpha_\mathrm{rec}(t) &= \mathrm{St}_\mathrm{in} c_p \frac{1}{A_\mathrm{cross}(t)} \dot{m}_\mathrm{in}(t - t_0) \\ &+ \mathrm{St}_\mathrm{out} c_p \frac{1}{A_\mathrm{cross}(t)} |\dot{m}_\mathrm{out}| \\ &+ \left(\mathrm{St}_p \frac{u_p(t)}{u_m} + \mathrm{St}_m\right) \rho_\mathrm{isen}(T_\mathrm{gas}) u_m c_p \end{aligned}$$

2.4 Matching the dimensionless numbers

The unknown dimensionless numbers $\mathrm{St_{in}}$, $\mathrm{St_{out}}$, $\mathrm{St_p}$, $\mathrm{St_m}$ are chosen such that the for a given set of process parameters the reconstructed heat flux approximates the numerically computed heat flux best.

Thus we minimize a functional which measures the distance between $\dot{Q}_{\mathrm{num}}$ and $\dot{Q}_{\mathrm{rec}}$.

$$\mathcal{F}_i(\mathrm{St_{in}}, \mathrm{St_{out}}, \mathrm{St_p}, \mathrm{St_m}) = \int_0^{t_{wc}} \left(Q_{\mathrm{num,i}}(t) - Q_{\mathrm{rec,i}}(t; \mathrm{St_{in}}, \mathrm{St_{out}}, \mathrm{St_p}, \mathrm{St_m})\right)^2 \, \mathrm{d}t \to \min \tag{14}$$

where $t_{wc} = 1/f$ is the revolution time and the index i is a numbering of the different parameter sets under consideration. .

In a first step the Stanton numbers are determine individually for every parameter set with index i.

In a second step we want to find universal values for the Stanton numbers. Thus we minimize the total approximation error

$$\mathcal{F}(\mathrm{St_{in}}, \mathrm{St_{out}}, \mathrm{St_p}, \mathrm{St_m}) = \sum_i \mathcal{F}_i(\mathrm{St_{in}}, \mathrm{St_{out}}, \mathrm{St_p}, \mathrm{St_m}) \tag{15}$$

The quality of the approximation is measured by comparing the difference of the numerical and reconstructed heat flux with the numerical heat flux:

$$\epsilon_i = \left(\frac{\int_0^{t_{wc}} (Q_{\mathrm{num,i}}(t) - Q_{\mathrm{rec,i}}(t))^2 \, \mathrm{d}t}{\int_0^{t_{wc}} (Q_{\mathrm{num,i}}(t))^2 \, \mathrm{d}t} \right)^{1/2} \tag{16}$$

Remarks

- In previous versions instead of the Stanton number $\mathrm{St_m}$ a Nusselt number was chosen:

  $$\dot{Q}_m = \mathrm{Nu} A(t) \frac{\lambda}{d} \Delta T$$

  Observing that the Nusselt number Nu turns out to be proportional to Reynolds-number $\mathrm{Nu} = \alpha \mathrm{Re}$ we write

  $$\dot{Q}_m = \alpha \mathrm{Re} A(t) \frac{\lambda}{d} \Delta T = \frac{\alpha}{\mathrm{Pr}} A(t)\, \rho_{\mathrm{in}} c_p u_m \Delta T = \mathrm{St_m} A(t)\, \rho_{\mathrm{in}} c_p u_m \Delta T.$$

  Thus we can interpret α/Pr as a Stanton-number $\mathrm{St_m}$ associated with the mean piston velocity u_m. Taking ρ_{isen} instead of ρ_{in} improves the recovery of the heat flux slightly.

- For a boundary layer flow the Stanton number is approximately

  $$St = \frac{c_w'}{2}$$

  (Reeynolds' analogy), where c_w' is the friction coefficient which can be determined using the logarithmic law as

  $$\frac{1}{\sqrt{c_w'}} = c_1 \ln\left(\sqrt{c_w'} \mathrm{Re_x}\right) + c2, \quad c_1 \approx 1.7, \quad c_2 \approx 3.0$$

  Evaluating these realtions we obtain Stanton numbers in range from 0.001 to 0.003 for Reynolds numbers between 10^4 and 10^6.

Re	10^4	10^5	10^6
St	2.5×10^{-3}	1.6×10^{-3}	1.1×10^{-3}

  It turns out the that the inflow and outflow Stanton numbers $\mathrm{St_{in}}$, $\mathrm{St_{out}}$ are of that magnitude. However the piston Stanton number turns out to be of the order 0.05. Thus our conclusion is that the refrence velocity is chosen to high.

3 Reconstruction of heat fluxes with Compress1d

In order to determine the heat transfer coefficients and the heat fluxes besides the thermodynamic properties of the gas and the geometric description of the compressor the mass flow in and out and the gas temperature in the compressor has to be known. All the necessary data is provided by the compressor simulation program Compress1D. As an additional feature compress 1D delivers

- the average temperature in the cylinder as function of the crank angle,
- the heat transfer coefficients for the piston rod, piston, cylinder head and cylinder barrel,
- if a wall temperature is specified the heat fluxes through these surfaces.

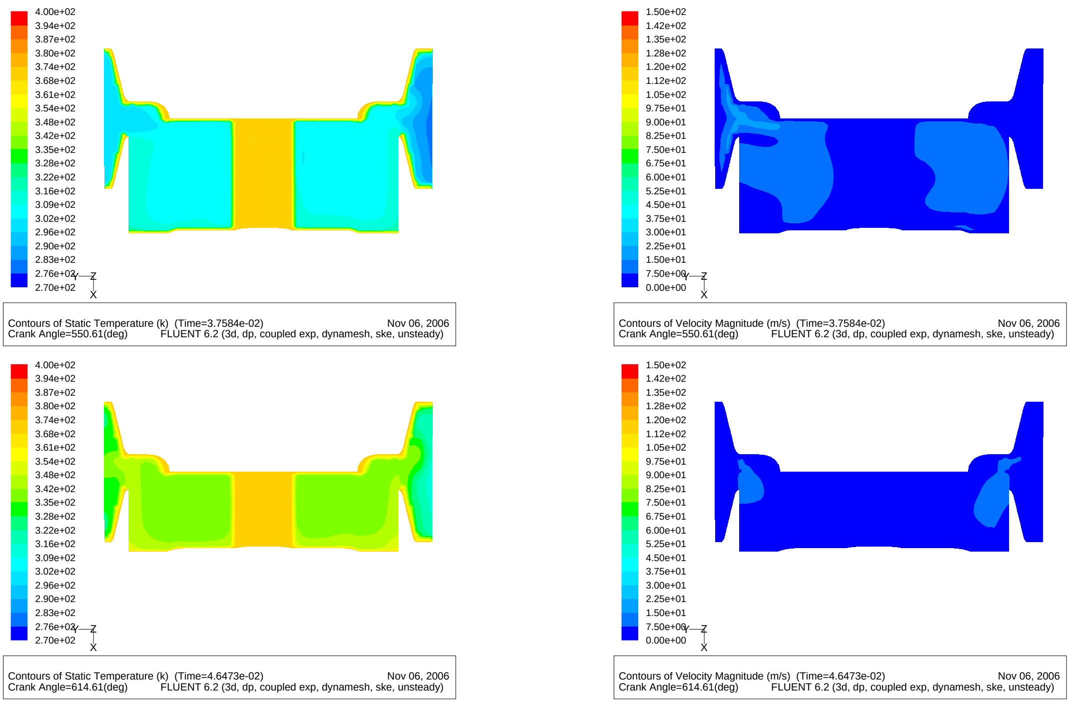
4 Model verification

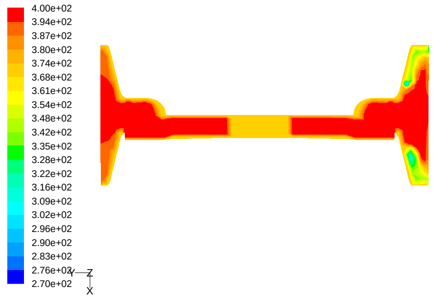
In this section we will discuss if and how the results depend on the assumptions of the reconstruction and what are the limits of validity of the present approach.

4.1 Uniform bulk temperature

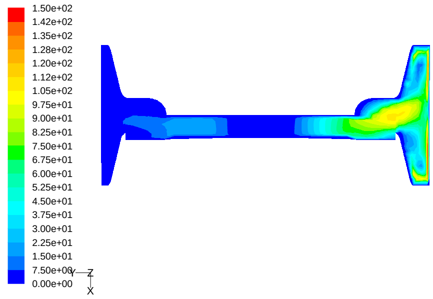
In the following we want to check the assumption that the gas temperature in the cylinder is uniform. In figure gastemp the temperature distribution in the plane of symmetry is shown for different crank angles.

At a crnk angle of 4° shortly after the deap point with smallest volume the air in the gap between the piston and cylinder head has the wall temperature. Due due the high pressure the air in the valve pockets is much hotter than in the gap between the piston and the cylinder head. During the the initial expansion this temperature distribution remains. When the suction valve opens cold gas flows into the compression chamber. Due to the rapid expansion the gas in the pressure valve pocket cools down rapidly below the inlet temperature. Near the dead point (174°) a cold jet emanating from the suction valve can be seen.

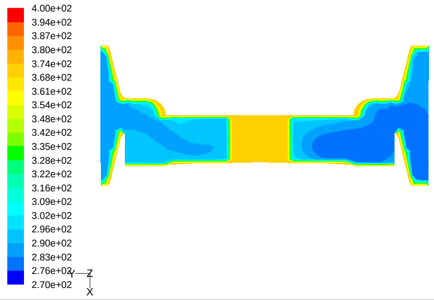




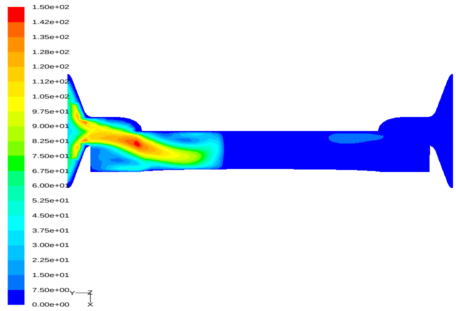
Contours of Static Temperature (k) (Time=5.4718e-02) Nov 06, 2006
Crank Angle=673.97(deg) FLUENT 6.2 (3d, dp, coupled exp, dynamesh, ske, unsteady)



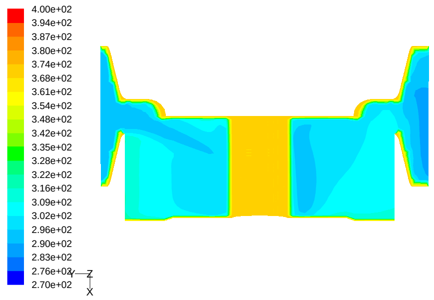
Contours of Velocity Magnitude (m/s) (Time=5.4718e-02) Nov 06, 2006
Crank Angle=673.97(deg) FLUENT 6.2 (3d, dp, coupled exp, dynamesh, ske, unsteady)



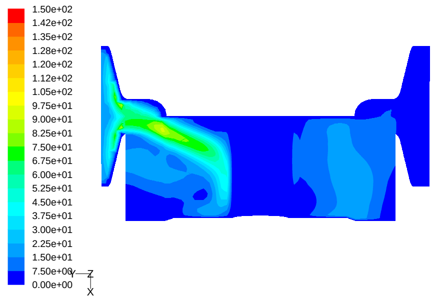
Contours of Static Temperature (k) (Time=7.1474e-02) Nov 06, 2006
Crank Angle=794.61(deg) FLUENT 6.2 (3d, dp, coupled exp, dynamesh, ske, unsteady)



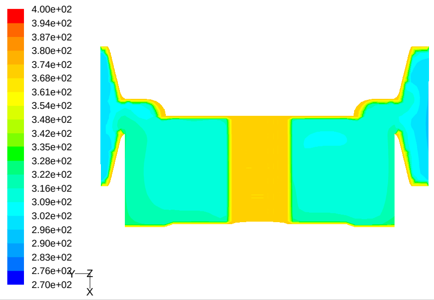
Contours of Velocity Magnitude (m/s) (Time=7.1474e-02) Nov 06, 2006
Crank Angle=794.61(deg) FLUENT 6.2 (3d, dp, coupled exp, dynamesh, ske, unsteady)



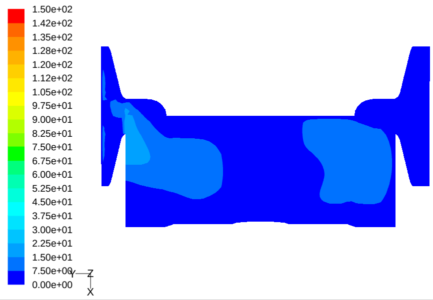
Contours of Static Temperature (k) (Time=8.0613e-02) Nov 06, 2006
Crank Angle=860.41(deg) FLUENT 6.2 (3d, dp, coupled exp, dynamesh, ske, unsteady)



Contours of Velocity Magnitude (m/s) (Time=8.0613e-02) Nov 06, 2006
Crank Angle=860.41(deg) FLUENT 6.2 (3d, dp, coupled exp, dynamesh, ske, unsteady)



Contours of Static Temperature (k) (Time=8.9640e-02) Nov 06, 2006
Crank Angle=925.41(deg) FLUENT 6.2 (3d, dp, coupled exp, dynamesh, ske, unsteady)



Contours of Velocity Magnitude (m/s) (Time=8.9640e-02) Nov 06, 2006
Crank Angle=925.41(deg) FLUENT 6.2 (3d, dp, coupled exp, dynamesh, ske, unsteady)

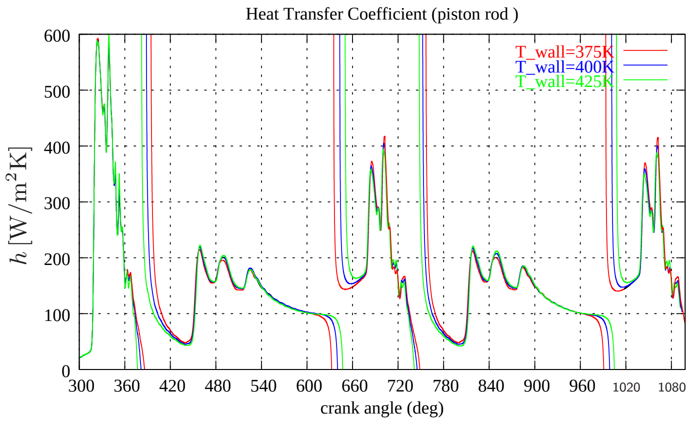


Figure 1: Heat flux coefficient determined for different wall temperatures

4.2 Dependence of the Stanton numbers on the wall temperature

The goal of the analysis is the reconstruction of the heat transfer coefficients for the surfaces of the compression chamber. As a result of the simulation the total heat fluxes $\dot{Q}_i$, $i = rmhead, pist, prod, side$ through the surfaces are obtained. By referring the heat flux density to the difference between the wall temperature and the bulk temperature the heat transfer coefficients are obtained. If the bulk temperature is close to or equal zero the wall temperature the average heat transfer coefficient is singular. Therefore the heat flux and not the heat transfer coefficient will be reconstructed.

In order to verify if the heat transfer coefficients depend on the wall temperature we perform the simulation for three different wall temperatures $T_w = 375$K, $T_w = 400$K and $T_w = 425$K, respectively.

In figure 1 the heat transfer coefficients for for these three wall temperatures is show as a function of the crank angle. During every working cycle the bulk temperature passes the wall wall temperature twice. Thus two singularities are present. The positions of the the singulariteis depend obviously on the wall temperature. But expect in the vicinity of the singularities the heat transfer coefficients are identical. Thus we conclude that the Stanton numbers do not depend on the wall temperature either.

4.3 Uniform wall temperature

5 Results

Simulations for air and methane have been performed. In the tables ?? and ?? the process parameters of the simulations are listed. The results for the Stanton numbers $\mathrm{St}_{\mathrm{in}}$, $\mathrm{St}_{\mathrm{out}}$, St_{p} St_{m} for the different faces of the compression chamber are listed in the tables ??, ??, ??, ?? for air in the tables ??, ??, ??, ?? for methane.

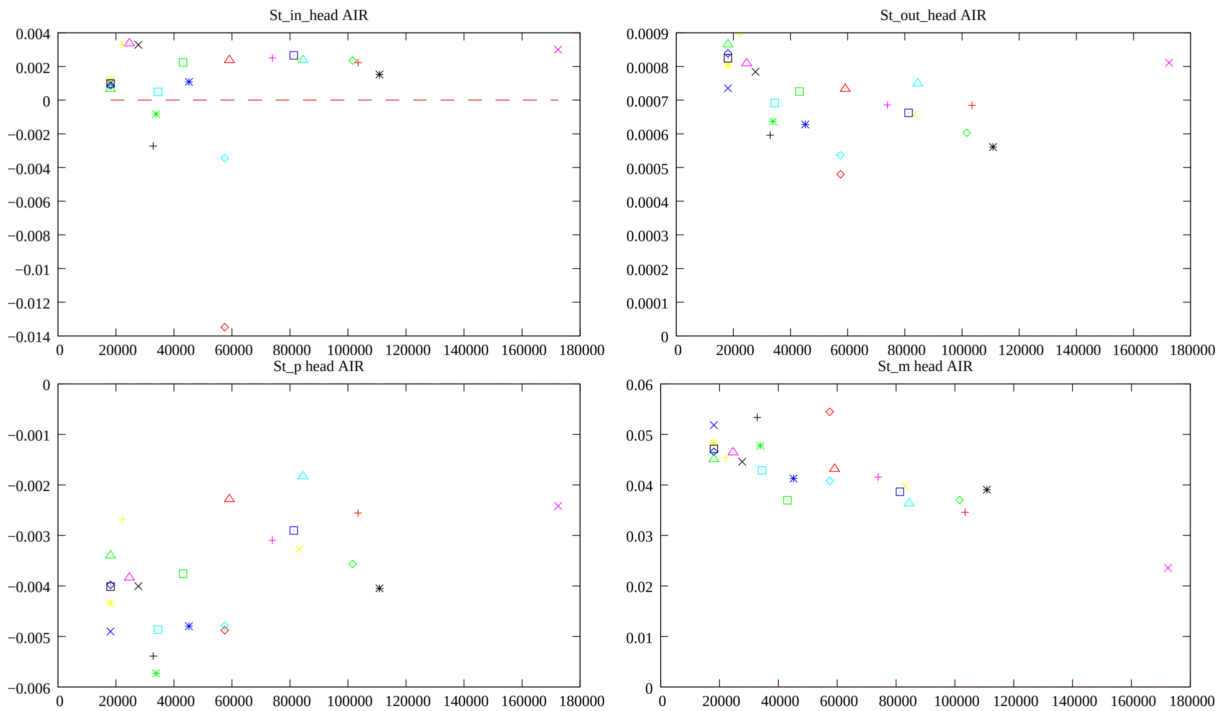
5.1 Air

case	h [mm]	n [1/min]	p_{in} [bar]	p_{out} [bar]	d_{rod} [mm]	
1	80	2000	1	5	45	+
2	90	980	1	5	45	×
3	110	1500	1	5	45	✳
4	140	1200	1	5	45	□
5	140	2000	1	5	45	◇
6	80	1500	1	3	45	△
7	90	1200	1	3	45	+
8	90	1500	1	3	45	×
9	110	2000	1	3	45	✳
10	140	1500	1	3	45	□
11	140	2000	1	3	45	◇
12	80	1200	3	9	45	△
13	80	1500	3	9	45	+
14	90	1500	3	9	45	×
15	90	2000	3	9	45	✳
16	110	1200	3	9	45	□
17	110	1500	3	9	45	◇
18	140	980	3	9	45	△
19	140	1200	3	9	45	+
20	140	2000	3	9	45	×
21	90	980	1	5	50	✳
22	90	980	1	5	55	□
23	90	980	1	5	60	◇
24	90	980	1	5	65	△

Table 1: Paramters of simulations for air

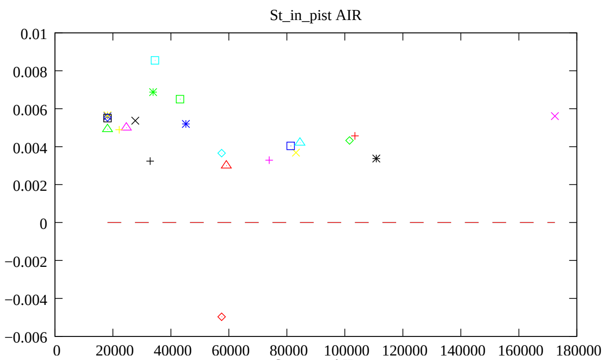
case	Re	St_{in}	St_{out}	St_p	St_m	error	error (aver)
1	32848.	-0.00272	-0.000596	-0.00538	0.0533	0.18	0.25
2	18107.	0.00101	-0.000736	-0.00490	0.0518	0.19	0.29
3	33874.	-0.000828	-0.000636	-0.00573	0.0477	0.14	0.22
4	34490.	0.000491	-0.000691	-0.00486	0.0428	0.14	0.20
5	57484.	-0.00135	-0.000480	-0.00487	0.0544	0.19	0.26
6	24636.	0.00337	-0.000809	-0.00383	0.0464	0.10	0.25
7	22172.	0.00331	-0.000894	-0.00268	0.0453	0.11	0.26
8	27715.	0.00328	-0.000784	-0.00400	0.0445	0.097	0.22
9	45166.	0.00108	-0.000627	-0.00479	0.0412	0.105	0.14
10	43113.	0.002239	-0.000725	-0.00375	0.0369	0.111	0.12
11	57484.	-0.00344	-0.000536	-0.00478	0.0407	0.144	0.20
12	59126.	0.00237	-0.000733	-0.00228	0.0431	0.102	0.19
13	73908.	0.00250	-0.000685	-0.00309	0.0415	0.095	0.16
14	83146.	0.00246	-0.000657	-0.00327	0.0397	0.090	0.13
15	110862.	0.00152	-0.000560	-0.00404	0.0390	0.093	0.12
16	81298.	0.00265	-0.000662	-0.00290	0.0386	0.097	0.14
17	101623.	0.00235	-0.000603	-0.00356	0.0369	0.087	0.10
18	84501.	0.00239	-0.000749	-0.00182	0.0363	0.129	0.16
19	103471.	0.00223	-0.000684	-0.00255	0.0345	0.120	0.13
20	172452.	0.00300	-0.000810	-0.00241	0.0235	0.115	0.31
21	18107.	0.00121	-0.000805	-0.00433	0.0482	0.192	0.28
22	18107.	0.000985	-0.000824	-0.00401	0.0471	0.196	0.28
23	18107.	0.000873	-0.000838	-0.00397	0.0465	0.197	0.28
24	18107.	0.000663	-0.000865	-0.00339	0.0450	0.202	0.28

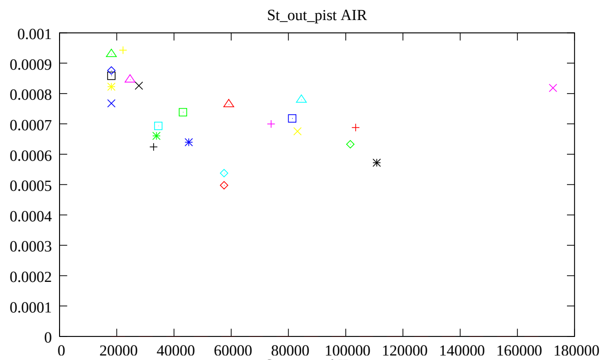
Table 2: Stannton number for the cylinder head and approximation error, air

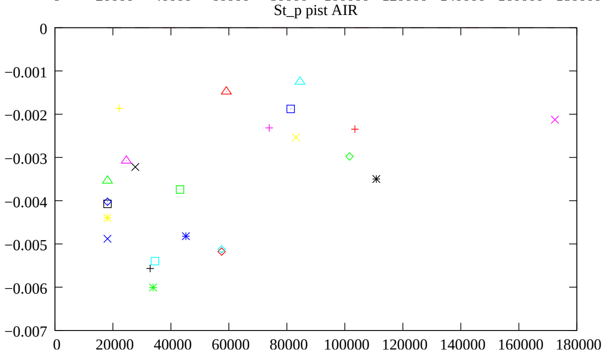


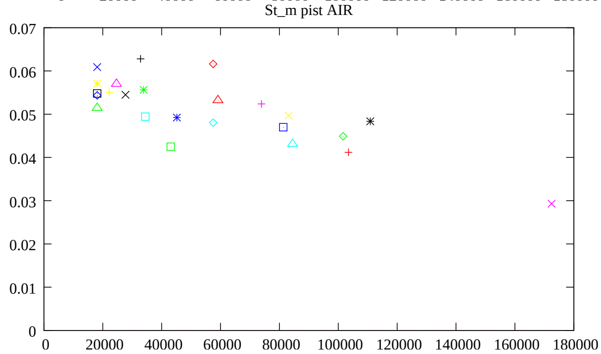
case	Re	St_{in}	St_{out}	St_p	St_m	error	error (aver)
1	32848.	0.00324	-0.000624	-0.00557	0.0628	0.173	0.249
2	18107.	0.00561	-0.000768	-0.00488	0.0609	0.175	0.288
3	33875.	0.00687	-0.000660	-0.00601	0.0556	0.145	0.243
4	34490.	0.00855	-0.000693	-0.00540	0.0494	0.141	0.222
5	57484.	-0.00497	-0.000498	-0.00518	0.0616	0.185	0.239
6	24636.	0.00500	-0.000846	-0.00307	0.0570	0.137	0.244
7	22172.	0.00489	-0.000943	-0.00186	0.0551	0.148	0.246
8	27716.	0.00537	-0.000826	-0.00322	0.0545	0.130	0.228
9	45166.	0.00520	-0.000640	-0.00482	0.0492	0.116	0.157
10	43113.	0.00650	-0.000739	-0.00374	0.0425	0.112	0.128
11	57484.	0.00366	-0.000538	-0.00513	0.0480	0.134	0.164
12	59126.	0.00300	-0.000764	-0.00148	0.0532	0.142	0.199
13	73908.	0.00329	-0.000700	-0.00232	0.0524	0.134	0.179
14	83147.	0.00369	-0.000676	-0.00254	0.0497	0.128	0.155
15	110862.	0.00337	-0.000572	-0.00350	0.0484	0.122	0.143
16	81299.	0.00404	-0.000718	-0.00188	0.0470	0.139	0.161
17	101624.	0.00432	-0.000633	-0.00298	0.0449	0.119	0.128
18	84502.	0.00421	-0.000779	-0.00125	0.0431	0.146	0.168
19	103471.	0.00457	-0.000688	-0.00235	0.0412	0.124	0.137
20	172452.	0.00561	-0.000819	-0.00213	0.0293	0.134	0.317
21	18107.	0.00565	-0.000823	-0.00440	0.0571	0.171	0.273
22	18107.	0.00550	-0.000859	-0.00407	0.0548	0.179	0.267
23	18107.	0.00554	-0.000876	-0.00402	0.0543	0.181	0.269
24	18107.	0.00492	-0.000930	-0.00354	0.0514	0.194	0.264

Table 3: Stannton number for the piston and approximation error, air



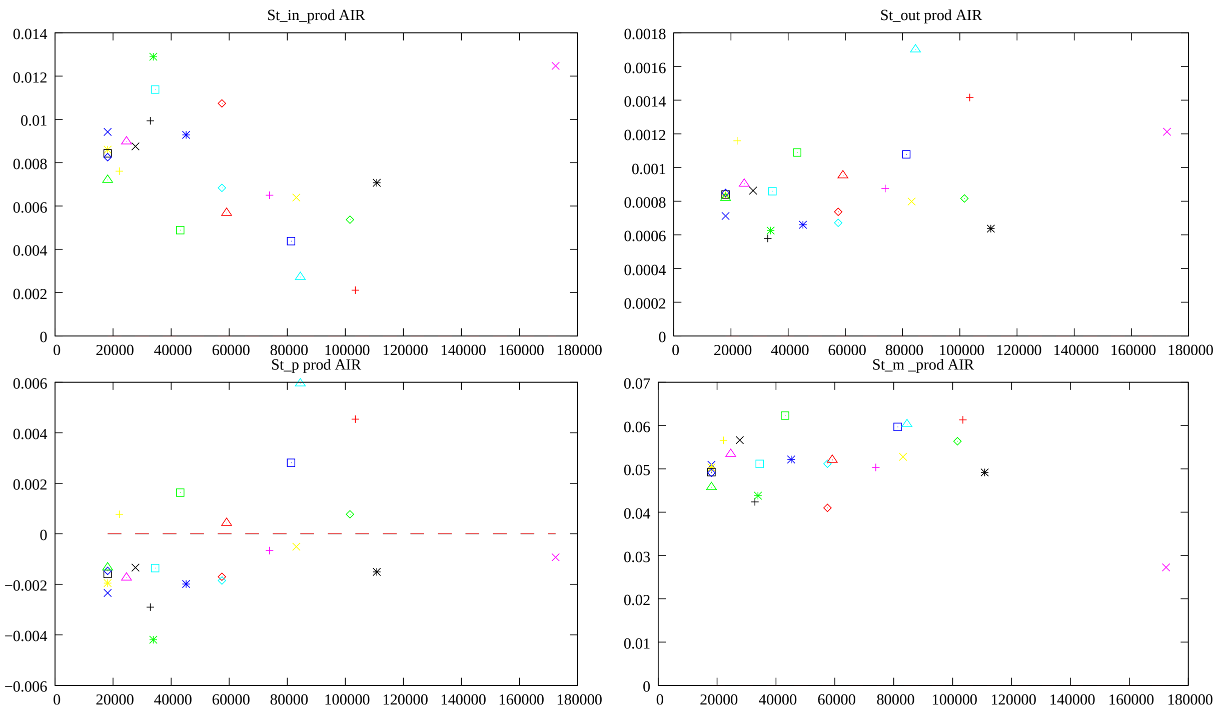






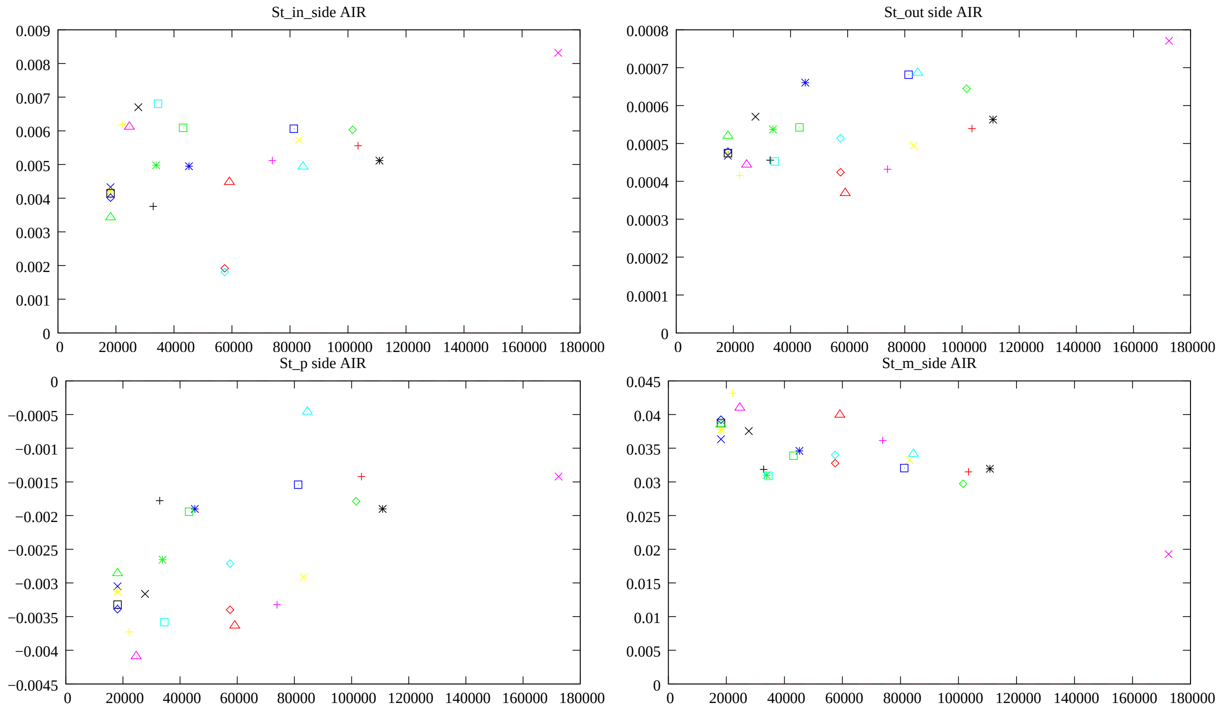
case	Re	St_{in}	St_{out}	St_p	St_m	error	error (aver)
1	6719.	0.00993	-0.000579	-0.00290	0.0424	0.095	0.117
2	3704.	0.00942	-0.000712	-0.00234	0.0509	0.100	0.137
3	6929.	0.01289	-0.000625	-0.00419	0.0438	0.098	0.160
4	7055.	0.01138	-0.000859	-0.00136	0.0511	0.130	0.201
5	11758.	0.01074	-0.000737	-0.00170	0.0410	0.106	0.114
6	5039.	0.00898	-0.000903	-0.00174	0.0534	0.091	0.137
7	4535.	0.00761	-0.001159	0.00077	0.0566	0.091	0.137
8	5669.	0.00875	-0.000863	-0.00134	0.0566	0.095	0.160
9	9239.	0.00929	-0.000660	-0.00199	0.0522	0.100	0.145
10	8819.	0.00489	-0.001089	0.00163	0.0623	0.094	0.164
11	11758.	0.00684	-0.000672	-0.00185	0.0512	0.085	0.100
12	12094.	0.00568	-0.000953	0.00043	0.0521	0.092	0.141
13	15118.	0.00650	-0.000876	-0.00066	0.0503	0.096	0.125
14	17007.	0.00639	-0.000798	-0.00051	0.0528	0.095	0.111
15	22676.	0.00707	-0.000637	-0.00151	0.0492	0.098	0.112
16	16629.	0.00438	-0.001078	0.00281	0.0597	0.094	0.120
17	20787.	0.00537	-0.000816	0.00077	0.0564	0.097	0.110
18	17284.	0.00272	-0.001701	0.00595	0.0603	0.093	0.153
19	21165.	0.00211	-0.001416	0.00454	0.0613	0.090	0.130
20	35274.	0.01247	-0.001212	-0.00093	0.0272	0.098	0.325
21	4115.	0.00860	-0.000836	-0.00195	0.0503	0.100	0.120
22	4527.	0.00843	-0.000840	-0.00159	0.0492	0.102	0.113
23	4938.	0.00825	-0.000849	-0.00147	0.0491	0.103	0.113
24	5350.	0.00720	-0.000819	-0.00133	0.0458	0.101	0.131

Table 4: Stannton number for the piston rod and approximation error, air



case	Re	St_{in}	St_{out}	St_p	St_m	error	error (aver)
1	32848.	0.00376	-0.000456	-0.00178	0.0319	0.124	0.209
2	18107.	0.00433	-0.000468	-0.00305	0.0363	0.100	0.177
3	33875.	0.00498	-0.000537	-0.00265	0.0310	0.113	0.131
4	34490.	0.00681	-0.000453	-0.00358	0.0309	0.088	0.127
5	57484.	0.00192	-0.000424	-0.00340	0.0328	0.094	0.153
6	24636.	0.00612	-0.000444	-0.00409	0.0410	0.068	0.185
7	22172.	0.00619	-0.000415	-0.00373	0.0432	0.103	0.230
8	27716.	0.00670	-0.000571	-0.00316	0.0375	0.068	0.170
9	45166.	0.00495	-0.000660	-0.00190	0.0346	0.101	0.130
10	43113.	0.00609	-0.000542	-0.00194	0.0339	0.097	0.145
11	57484.	0.00181	-0.000514	-0.00271	0.0340	0.095	0.143
12	59126.	0.00448	-0.000369	-0.00363	0.0400	0.132	0.198
13	73908.	0.00512	-0.000432	-0.00332	0.0361	0.080	0.120
14	83147.	0.00572	-0.000494	-0.00291	0.0332	0.083	0.102
15	110862.	0.00512	-0.000563	-0.00190	0.0320	0.081	0.098
16	81299.	0.00606	-0.000681	-0.00154	0.0321	0.108	0.122
17	101624.	0.00603	-0.000645	-0.00179	0.0297	0.094	0.096
18	84502.	0.00494	-0.000687	-0.00046	0.0342	0.101	0.127
19	103471.	0.00556	-0.000539	-0.00142	0.0315	0.091	0.100
20	172452.	0.00832	-0.000771	-0.00142	0.0193	0.060	0.223
21	18107.	0.00420	-0.000473	-0.00313	0.0377	0.092	0.183
22	18107.	0.00414	-0.000475	-0.00332	0.0387	0.091	0.193
23	18107.	0.00402	-0.000478	-0.00339	0.0392	0.090	0.199
24	18107.	0.00343	-0.000520	-0.00286	0.0385	0.103	0.211

Table 5: Stannton number for the piston rod and approximation error, air



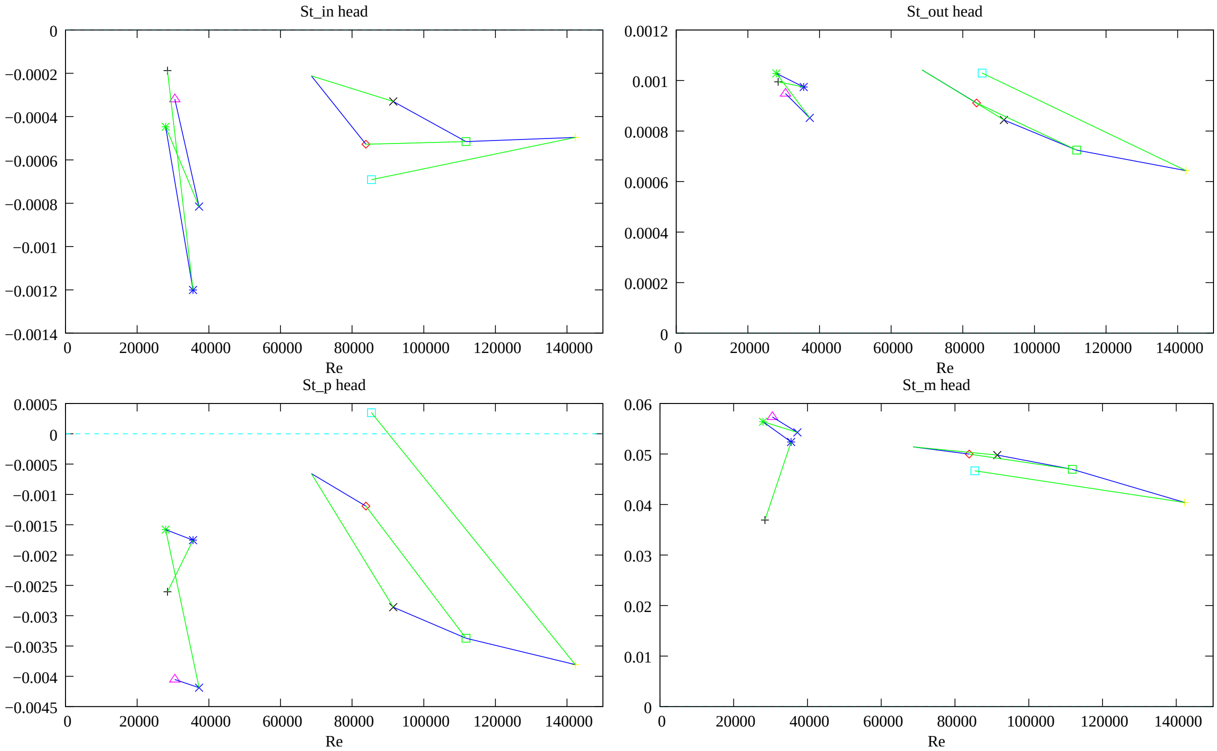
5.2 Methan CH_4

case	h [mm]	n [1/min]	p_{in} [bar]	p_{out} [bar]	d_{rod} [mm]	
1	140	1200	3	9	45	+
2	110	2000	1	3	45	×
3	110	1500	1	3	45	✳
4	140	1200	3	9	45	□
5	110	1500	3	9	45	◇
6	90	2000	1	3	45	△
7	140	2000	3	9	45	+
8	90	2000	3	9	45	×
9	140	1500	1	3	45	✳
10	110	2000	3	9	45	□
11	90	1500	3	9	45	◇

Table 6: Paramters of simulations for CH_4

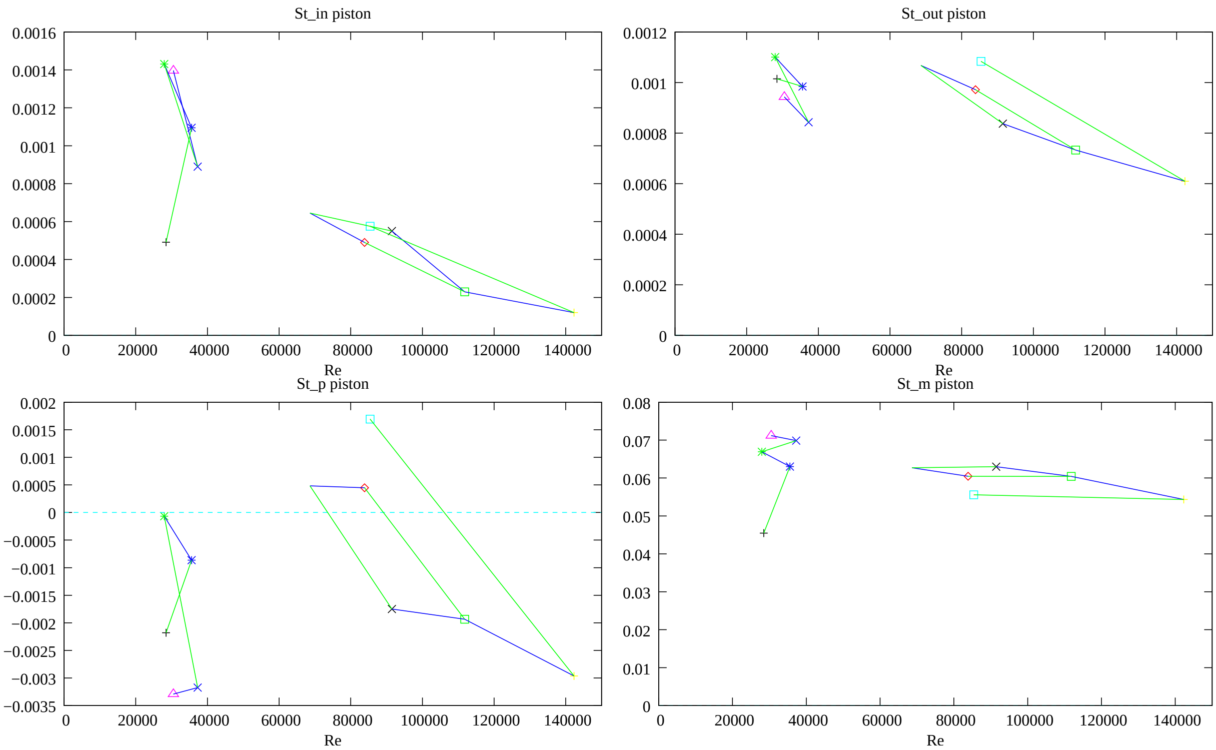
case	Re	St_{in}	St_{out}	St_p	St_m	error	error (aver)
1	18297.	0.00290	-0.001116	-0.00249	0.0516	0.138	0.118
2	37271.	0.00271	-0.000791	-0.00521	0.0454	0.113	0.298
3	27953.	0.00331	-0.000894	-0.00399	0.0470	0.137	0.187
4	85384.	0.00218	-0.000889	-0.00180	0.0397	0.147	0.236
5	83859.	0.00265	-0.000793	-0.00342	0.0417	0.118	0.179
6	30494.	0.00310	-0.000873	-0.00528	0.0478	0.120	0.144
7	142307.	0.00143	-0.000596	-0.00405	0.0364	0.135	0.230
8	91483.	0.00228	-0.000770	-0.00406	0.0425	0.106	0.175
9	35577.	0.00309	-0.000877	-0.00370	0.0422	0.147	0.132
10	111813.	0.00209	-0.000666	-0.00428	0.0404	0.103	0.193

Table 7: Stannton number for the cylinder head and approximation error, CH_4



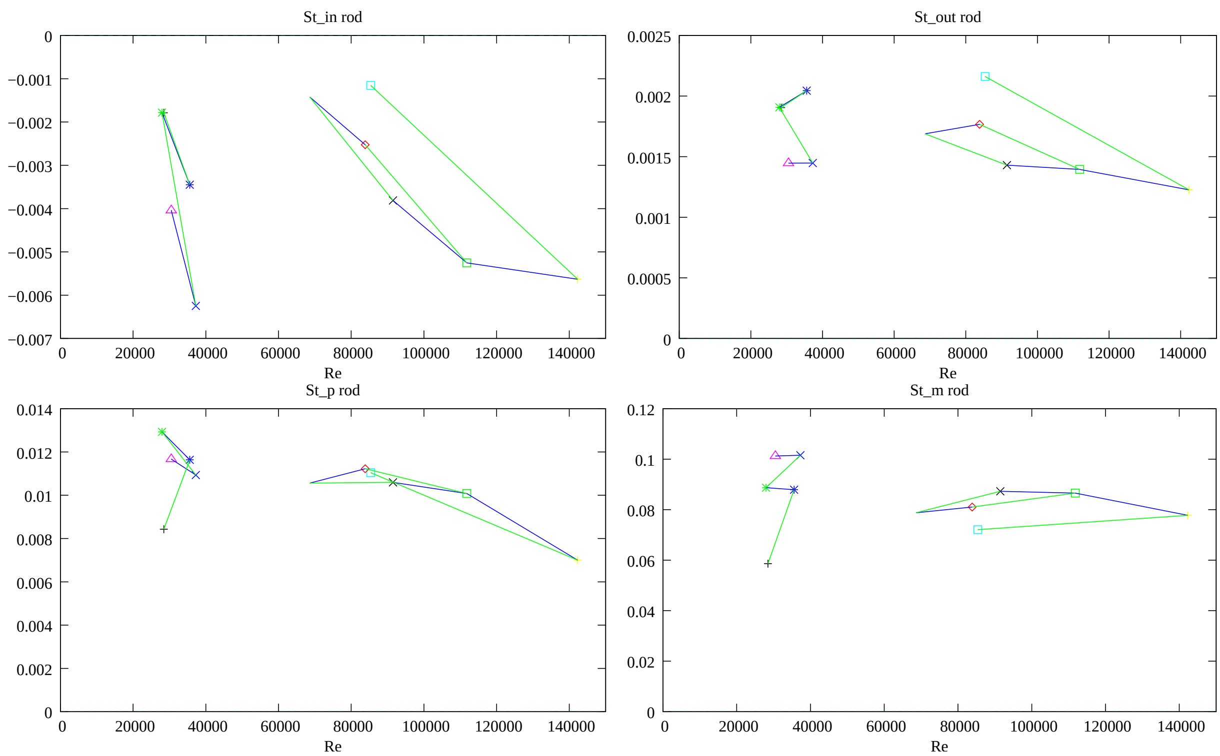
case	Re	St_{in}	St_{out}	St_p	St_m	error	error (aver)
1	18297.	0.00454	-0.001172	-0.00189	0.0613	0.145	0.142
2	37271.	0.00763	-0.000821	-0.00495	0.0539	0.116	0.238
3	27953.	0.00702	-0.000960	-0.00336	0.0539	0.136	0.206
4	85384.	0.00467	-0.000928	-0.00123	0.0463	0.149	0.225
5	83859.	0.00475	-0.000851	-0.00239	0.0498	0.141	0.167
6	30494.	0.00676	-0.000904	-0.00477	0.0571	0.124	0.151
7	142307.	0.00542	-0.000594	-0.00413	0.0438	0.121	0.227
8	91483.	0.00433	-0.000786	-0.00323	0.0527	0.127	0.144
9	35577.	0.00817	-0.000896	-0.00379	0.0476	0.128	0.143
10	111813.	0.00504	-0.000696	-0.00368	0.0487	0.121	0.190

Table 8: Stannton number for the piston and approximation error, CH_4



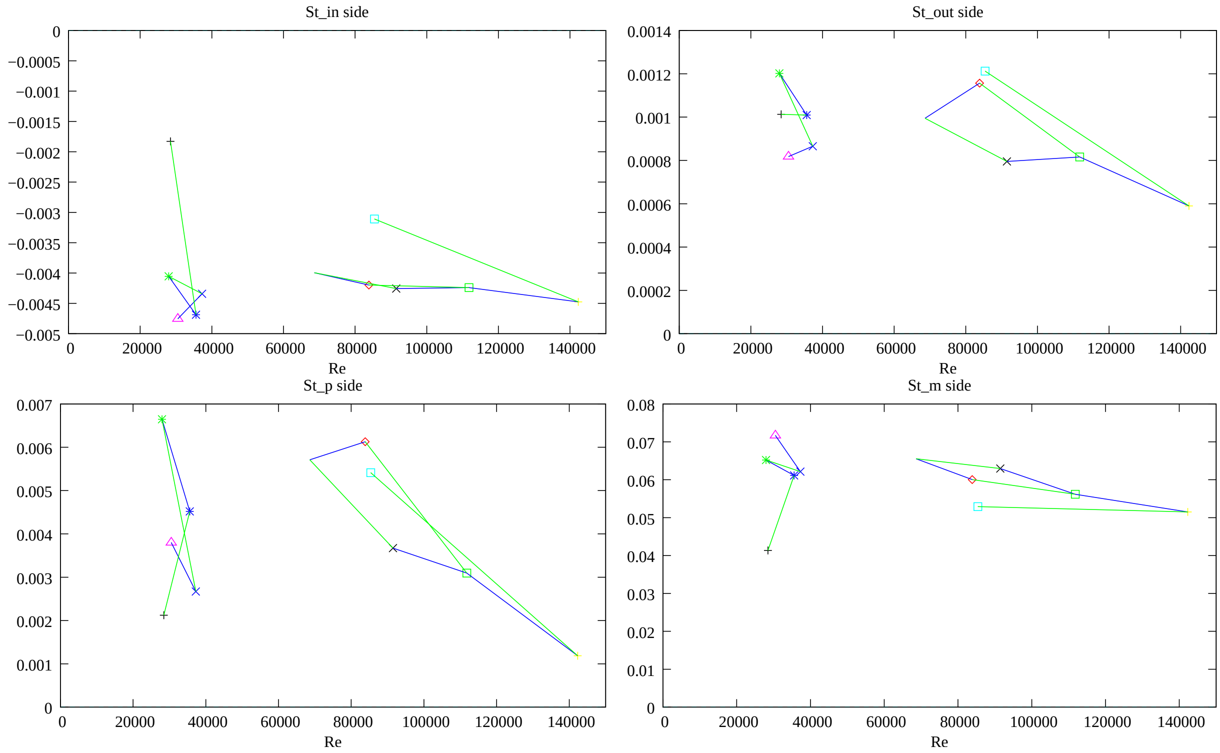
case	Re	St_{in}	St_{out}	St_p	St_m	error	error (aver)
1	3742.	0.00650	-0.001102	0.00129	0.0662	0.106	0.099
2	7624.	0.01044	-0.000793	-0.00213	0.0588	0.108	0.148
3	5718.	0.00806	-0.001108	0.00171	0.0653	0.113	0.179
4	17465.	0.00322	-0.001626	0.00629	0.0635	0.101	0.193
5	17153.	0.00558	-0.001047	0.00205	0.0612	0.105	0.137
6	6237.	0.01123	-0.000754	-0.00403	0.0541	0.093	0.110
7	29108.	0.00464	-0.000836	0.00106	0.0585	0.094	0.173
8	18712.	0.00760	-0.000774	-0.00192	0.0533	0.098	0.103
9	7277.	0.00586	-0.001382	0.00394	0.0694	0.115	0.109
10	22871.	0.00702	-0.000775	-0.00045	0.0566	0.104	0.197

Table 9: Stannton number for the piston rod and approximation error, CH_4



case	Re	St_{in}	St_{out}	St_p	St_m	error	error (aver)
1	18297.	0.00415	-0.000578	-0.00237	0.0527	0.154	0.112
2	37271.	0.00533	-0.000719	-0.00218	0.0371	0.094	0.268
3	27953.	0.00701	-0.000644	-0.00303	0.0382	0.088	0.114
4	85384.	0.00466	-0.000669	-0.00081	0.0372	0.108	0.179
5	83859.	0.00590	-0.000636	-0.00251	0.0342	0.106	0.126
6	30494.	0.00611	-0.000639	-0.00331	0.0380	0.061	0.113
7	142307.	0.00507	-0.000490	-0.00222	0.0329	0.090	0.125
8	91483.	0.00509	-0.000610	-0.00274	0.0344	0.063	0.097
9	35577.	0.00668	-0.000567	-0.00243	0.0377	0.101	0.072
10	111813.	0.00523	-0.000645	-0.00207	0.0320	0.073	0.170

Table 10: Stannton number for the side wall and approximation error, CH_4

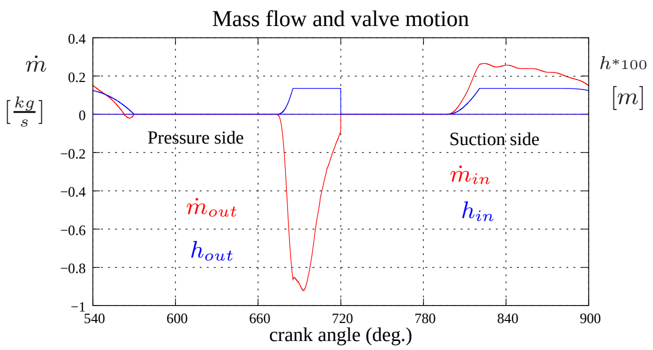


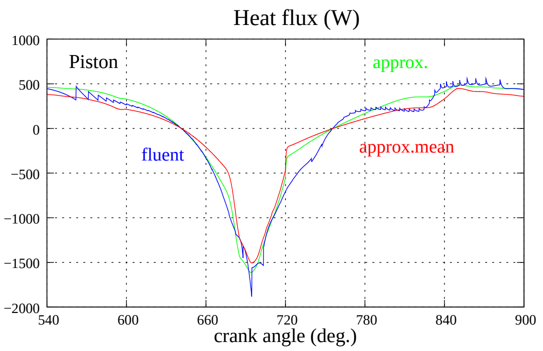
6 Protcol of the simulations

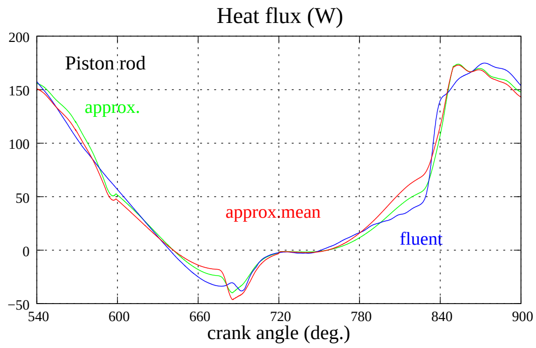
6.1 Case 1

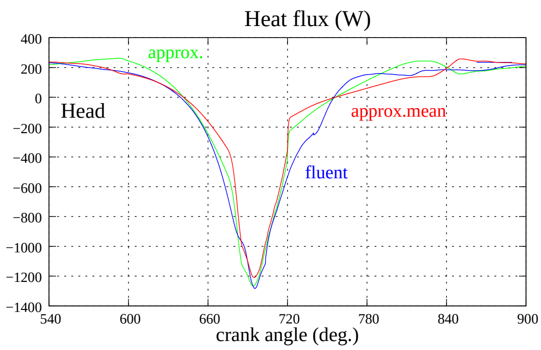
Values:

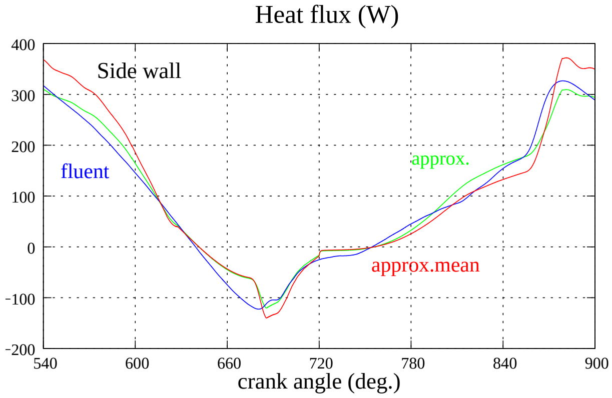
- Piston stroke: 80mm (standard value 90)
- Rod length: 250mm (standard value)
- Cra. speed: 2000 min^{-1} (standard value 980)
- Gas: air (standard value)
- $p_{in} = 1$bar, $p_{out} = 5$bar (standard $p_{in} = 1$, $p_{out} = 5$)









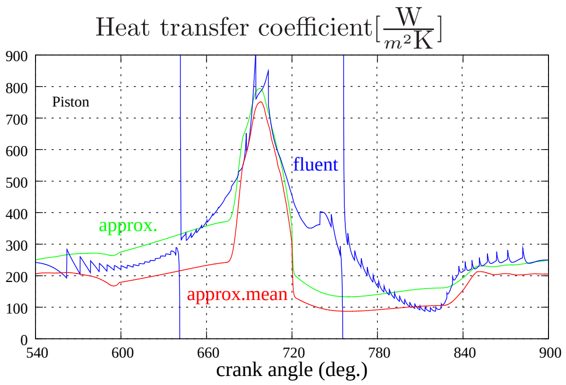


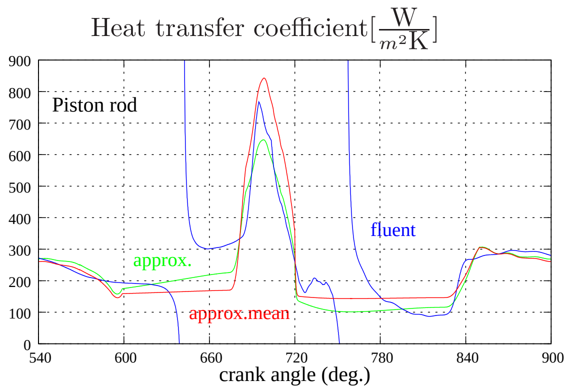
*The results valid for "half" of the compressor (axial symmetry)

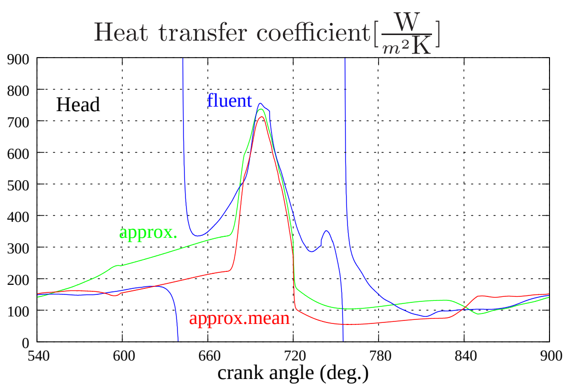
Tables of coefficients

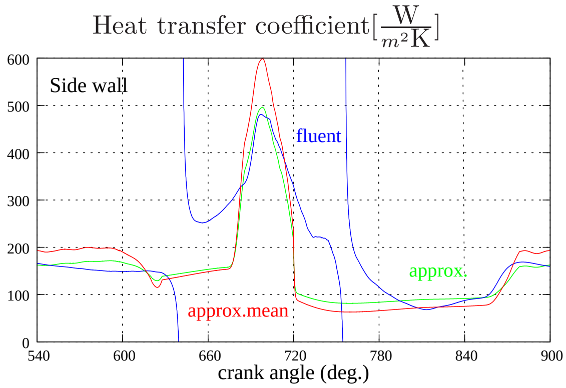
	St_{in}	St_{out}	St_k	Nu/Re	φ_0	error	error mean
Head	-0.00273	-0.00059	-0.0053897	0.053	-28.93	0.1826	0.2571
Piston rod	0.00993	-0.00058	-0.0029	0.0424	-28.93	0.0945	0.117
Piston	0.00324	-0.00062	-0.00557	0.06279	-28.93	0.1726	0.2485
Side wall	0.00376	-0.00046	-0.00178	0.03186	-57.87	0.1238	0.2093

6.1.1 Heat transfer coefficient results





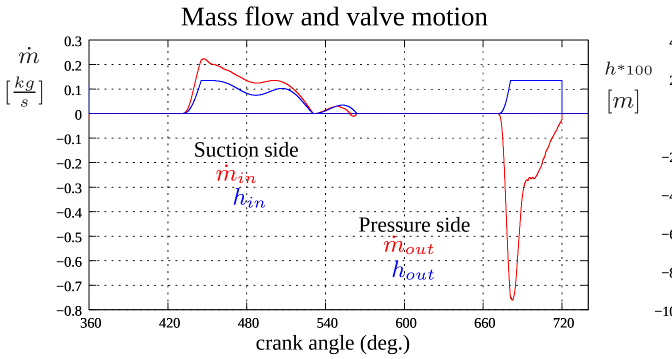


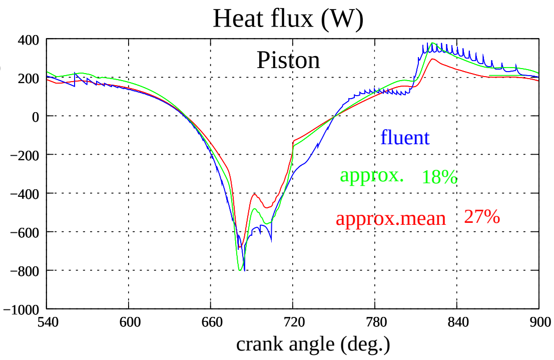


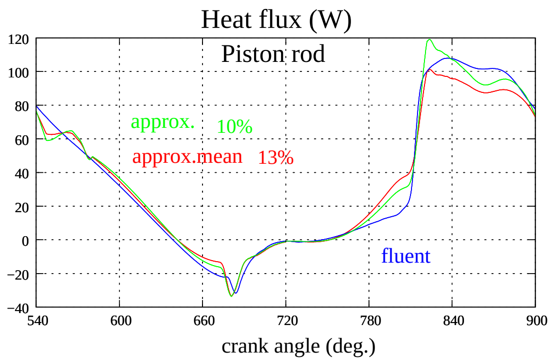
6.2 Case 2

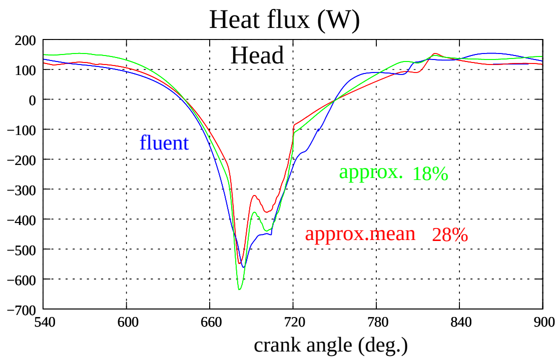
Values:

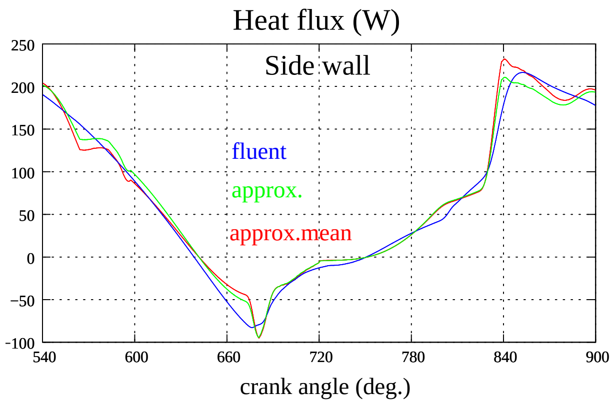
- Piston stroke: 80mm (standard value 90)
- Rod length: 250mm (standard value)
- Cra. speed: 980 min^{-1} (standard value 980)
- Gas: air (standard value)
- p_{in} = 1bar, p_{out} = 5bar (standard $p_{in} = 1$, $p_{out} = 5$)









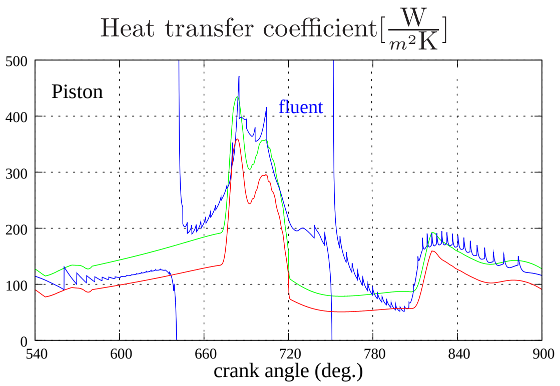


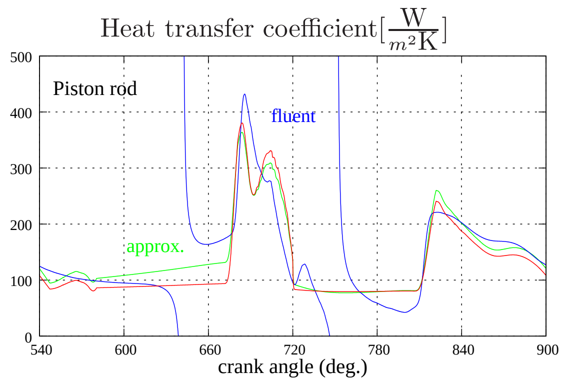
*The results valid for "half" of the compressor (axial symmetry)

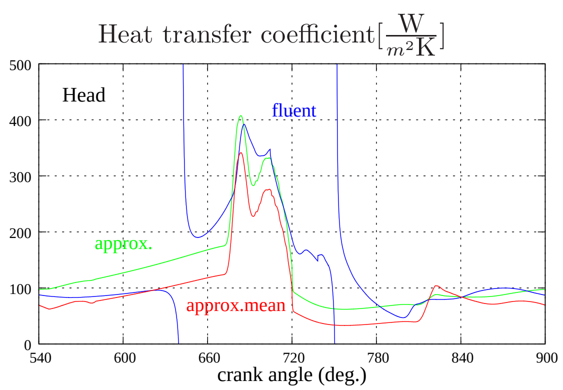
Tables of coefficients

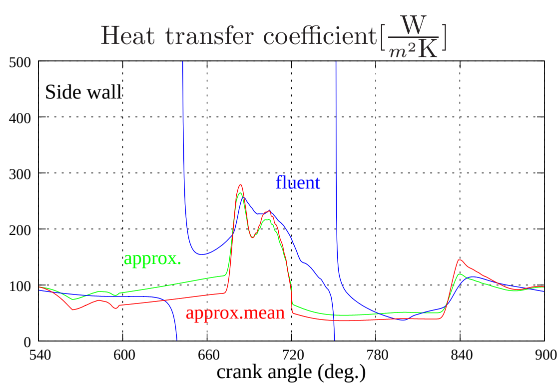
	St_{in}	St_{out}	St_k	Nu/Re	φ_0	error	error mean
Head	0.00101	-0.00074	-0.0049	0.0518	-16.89	0.1918	0.2787
Piston rod	0.0094	-0.00071	-0.0023	0.0509	-16.89	0.0998	0.1374
Piston	0.00561	-0.000768	-0.00488	0.0609	-16.89	0.1755	0.2775
Side wall	0.00433	-0.00047	-0.00305	0.0363	-33.79	0.09999	0.1773

6.2.1 Heat transfer coefficient results





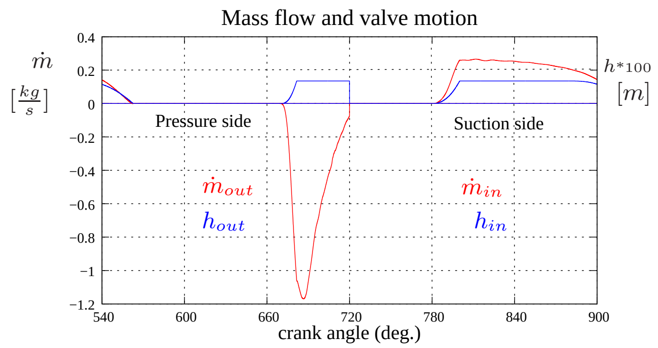


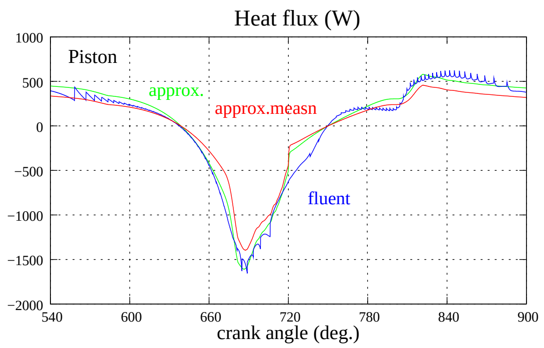


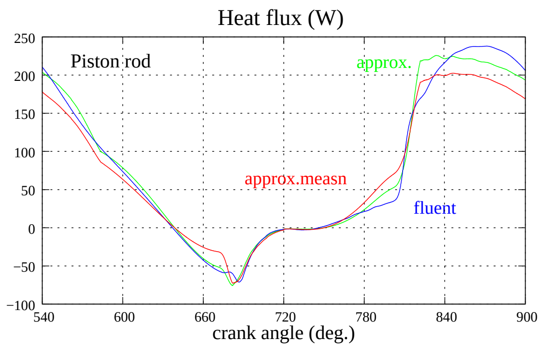
6.3 Case 3

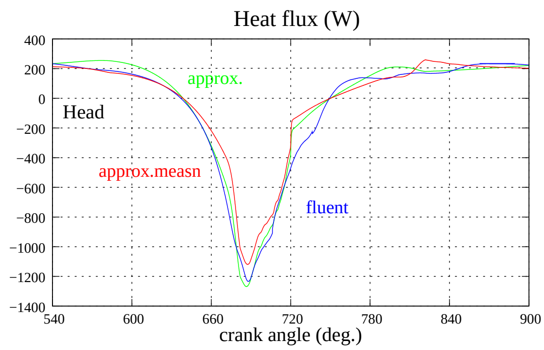
Values:

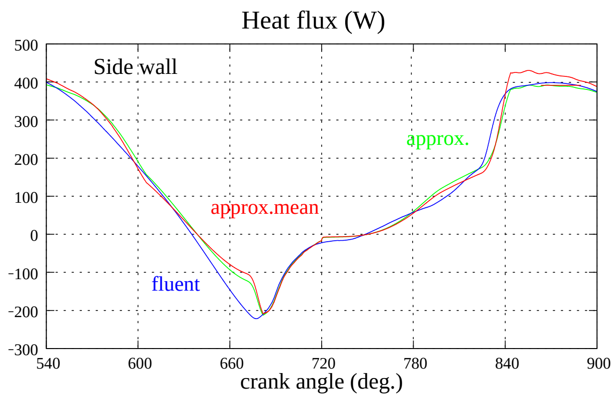
- Piston stroke: 110mm (standard value 90)
- Rod length: 250mm (standard value)
- Cra. speed: 1500 min^{-1} (standard value 980)
- Gas: air (standard value)
- $p_{in} = 1\text{bar}$, $p_{out} = 5\text{bar}$ (standard $p_{in} = 1$, $p_{out} = 5$)









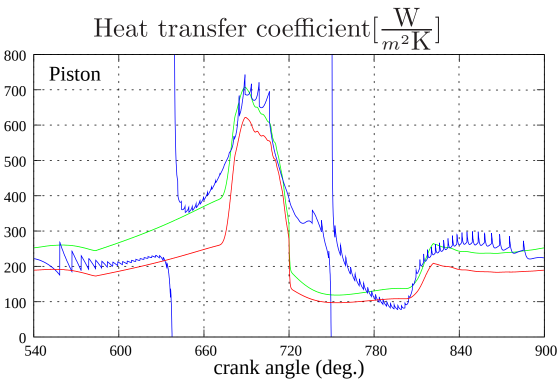


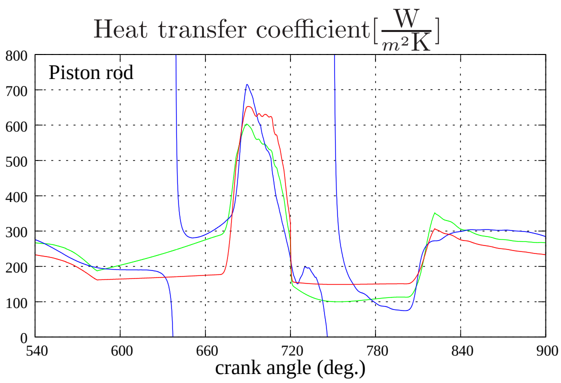
*The results valid for "half" of the compressor (axial symmetry)

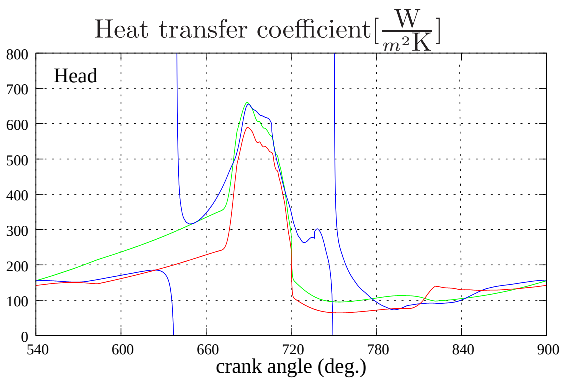
Tables of coefficients

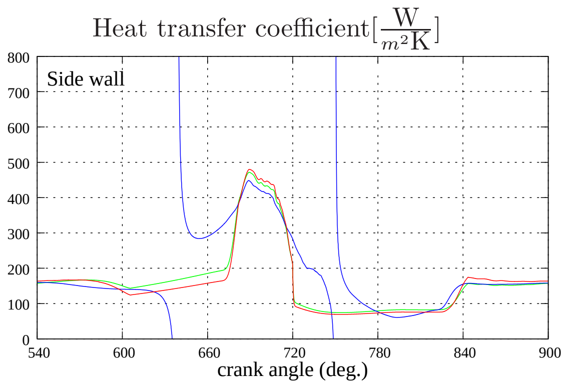
	St_{in}	St_{out}	St_k	Nu/Re	φ_0	error	error mean
Head	-0.00083	-0.000637	-0.005732	0.04775	-21.78	0.1453	0.2279
Piston rod	0.01289	-0.000626	-0.004193	0.04382	-21.78	0.0976	0.1600
Piston	0.006874	-0.00066	-0.00601	0.05563	-21.78	0.1453	0.2427
Side wall	0.00498	-0.000537	-0.00265	0.03099	-43.57	0.1125	0.1315

6.3.1 Heat transfer coefficient results





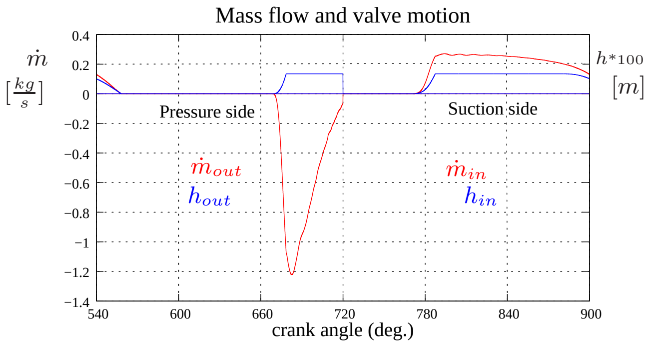


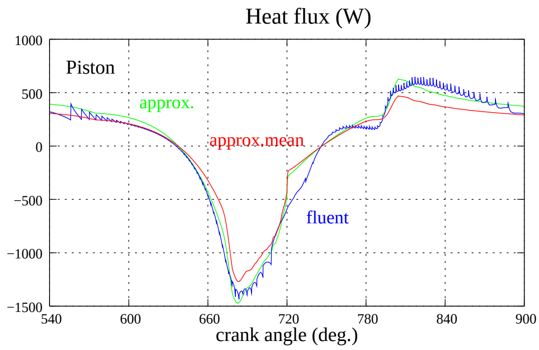


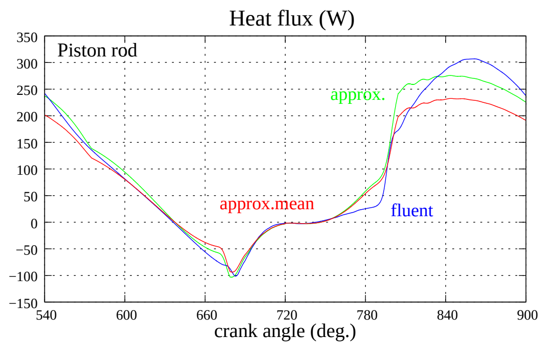
6.4 Case 4

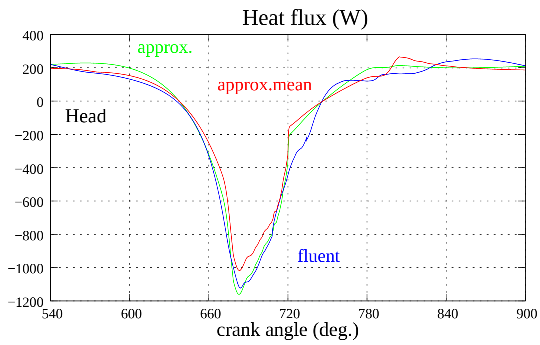
Values:

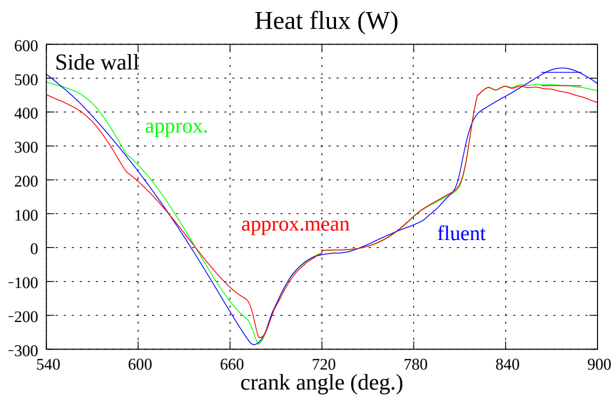
- Piston stroke: 140mm (standard value 90)
- Rod length: 250mm (standard value)
- Cra. speed: 1200 min^{-1} (standard value 980)
- Gas: air (standard value)
- p_{in} = 1bar, p_{out} = 5bar (standard $p_{in} = 1$, $p_{out} = 5$)









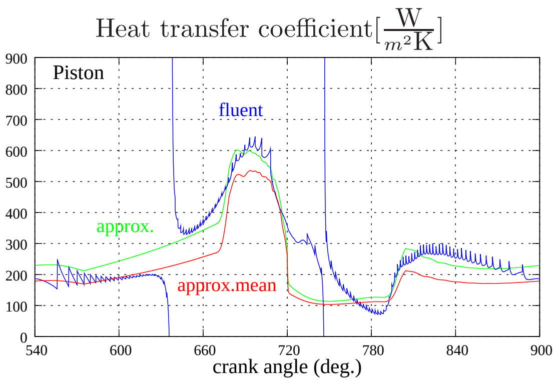


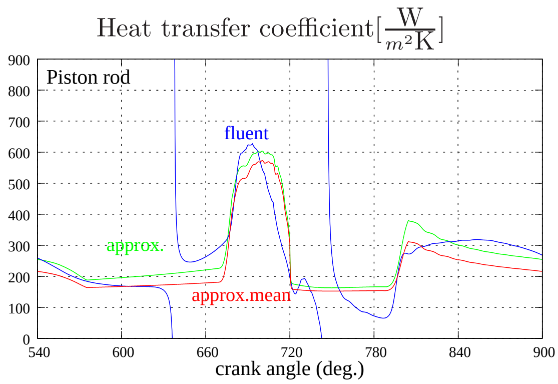
*The results valid for "half" of the compressor (axial symmetry)

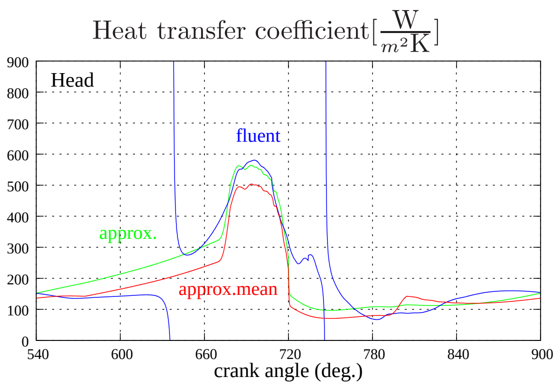
Tables of coefficients

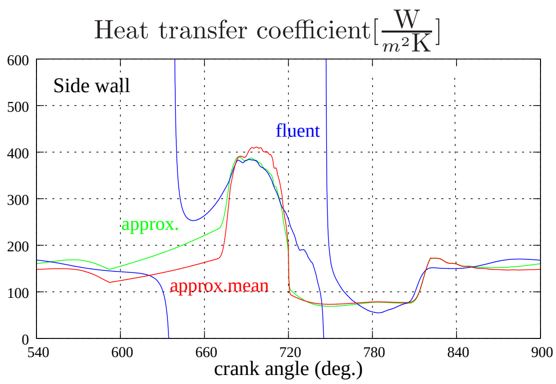
	St_{in}	St_{out}	St_k	Nu/Re	φ_0	error	error mean
Head	0.000491	-0.000692	-0.00486	0.04287	-17.12	0.1452	0.2007
Piston rod	0.01138	-0.000859	-0.001358	0.051146	-17.12	0.1300	0.2008
Piston	0.008546	-0.000693	0.005397	0.04941	-17.12	0.1415	0.2218
Side wall	0.00681	-0.0004527	-0.00486	0.0428722	-34.24	0.088	0.1270

6.4.1 Heat transfer coefficient results





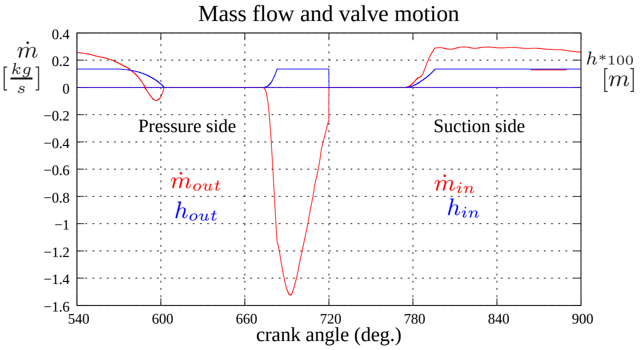


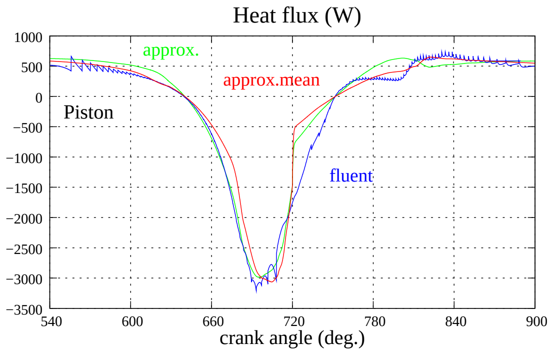


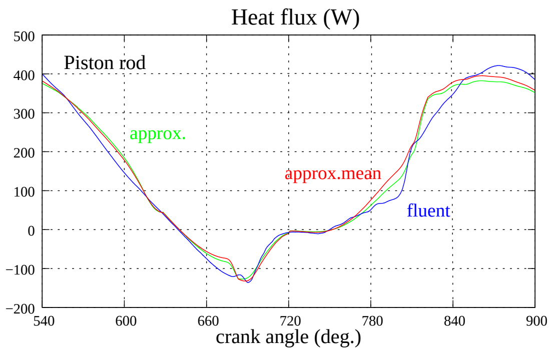
6.5 Case 5

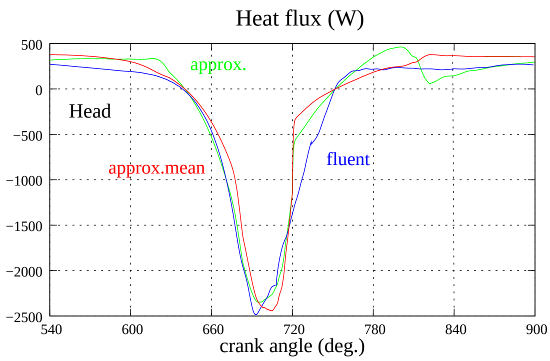
Values:

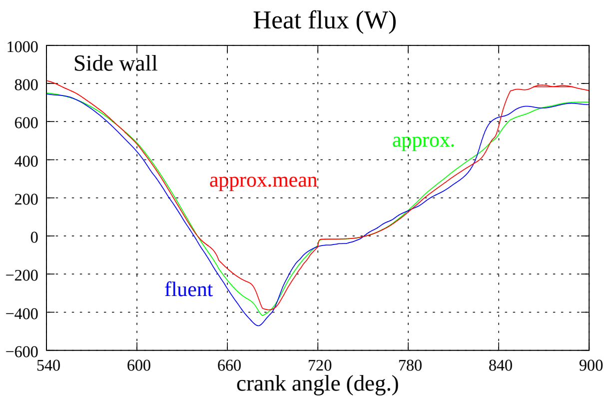
- Piston stroke: 140mm (standard value 90)
- Rod length: 250mm (standard value)
- Cra. speed: 2000 min^{-1} (standard value 980)
- Gas: air (standard value)
- $p_{in} = 1$bar, $p_{out} = 5$bar (standard $p_{in} = 1$, $p_{out} = 5$)









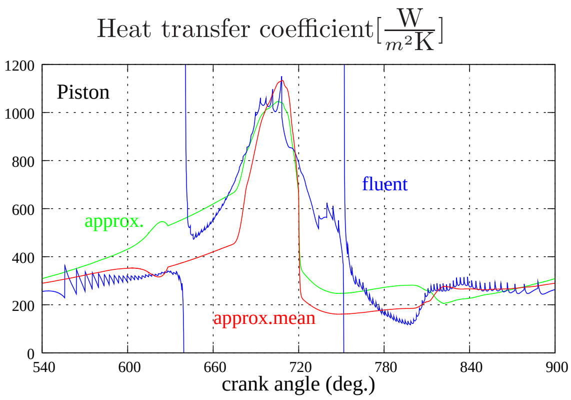


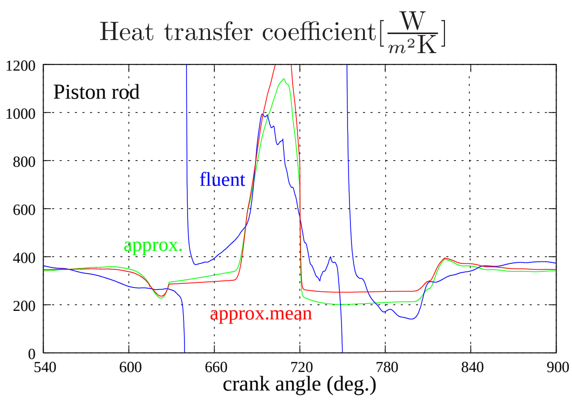
*The results valid for “half” of the compressor (axial symmetry)

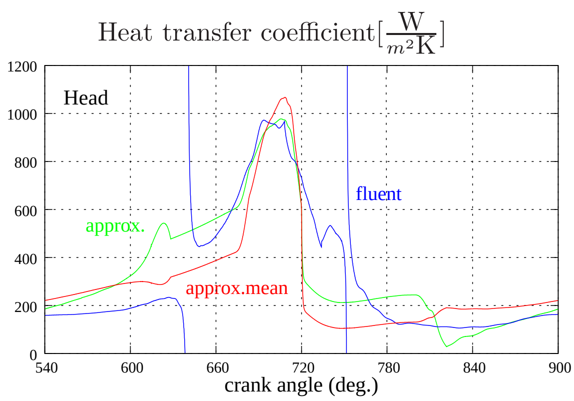
Tables of coefficients

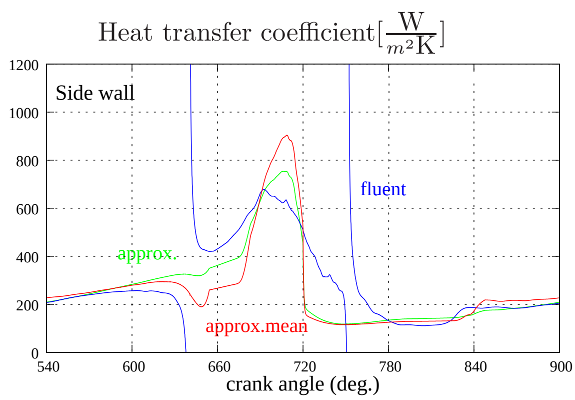
	St_{in}	St_{out}	St_k	Nu/Re	φ_0	error	error mean
Head	-0.01348	-0.00048	-0.00488	0.05447	-25.97	0.1918	0.2693
Piston rod	0.01074	-0.00074	-0.001698	0.04098	-25.97	0.1057	0.1137
Piston	-0.00497	-0.000498	-0.005176	0.06163	-25.97	0.1851	0.2392
Side wall	0.00192	-0.00042	-0.003399	0.03277	-51.95	0.0937	0.1527

6.5.1 Heat transfer coefficient results





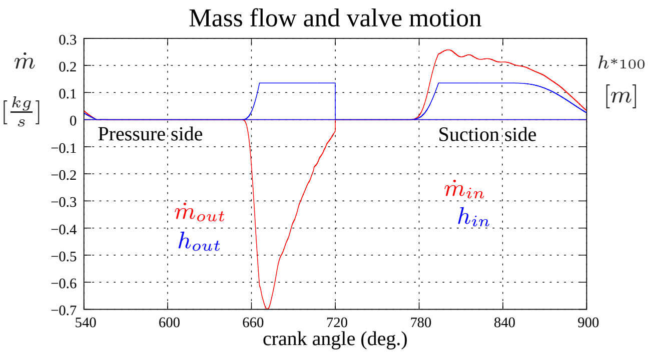


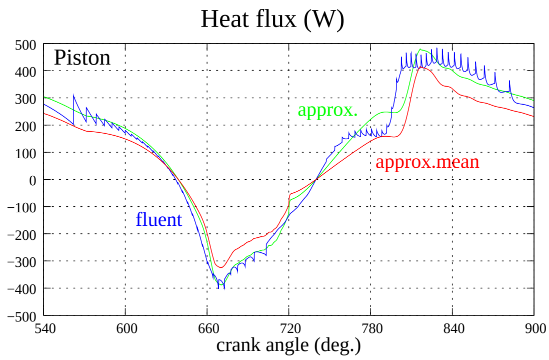


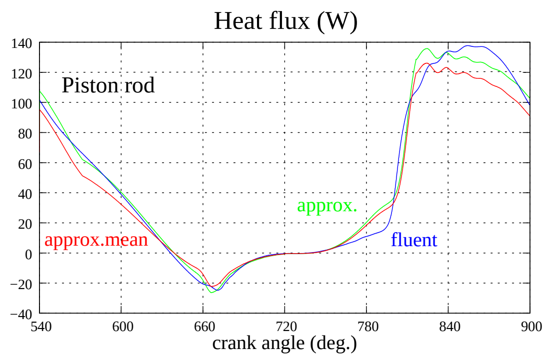
6.6 Case 6

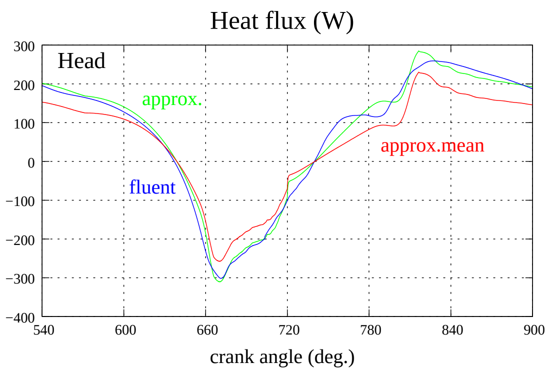
Values:

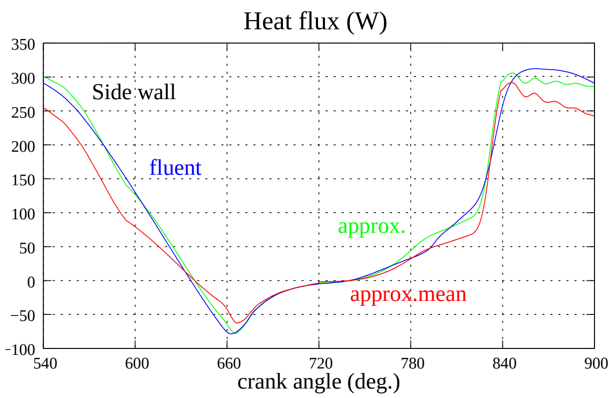
- Piston stroke: 80mm (standard value 90)
- Rod length: 250mm (standard value)
- Cra. speed: 1500 $\min^{-1}$ (standard value 980)
- Gas: air (standard value)
- $p_{in} = 1$bar, $p_{out} = 3$bar (standard $p_{in} = 1$, $p_{out} = 5$)









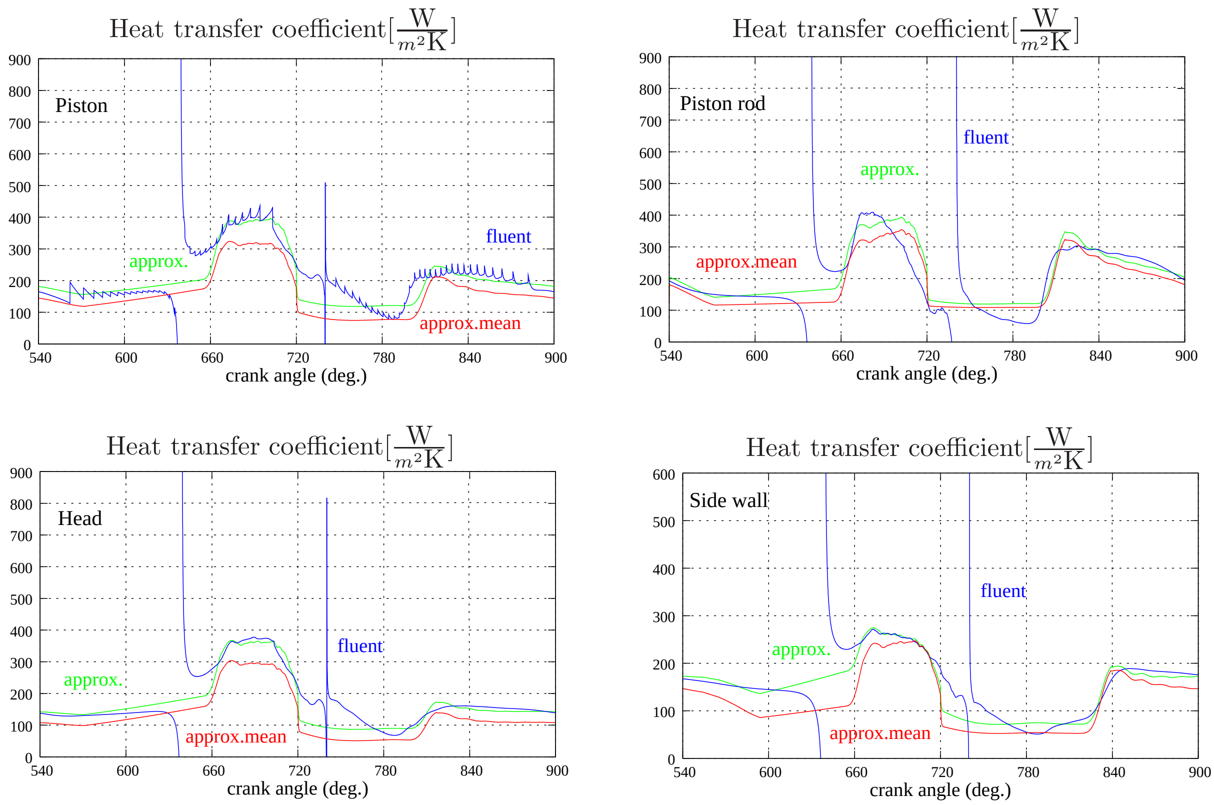


*The results valid for "half" of the compressor (axial symmetry)

Tables of coefficients

	St_{in}	St_{out}	St_k	Nu/Re	φ_0	error	error mean
Head	0.0034	-0.00081	-0.0038	0.0464	-22.50	0.1017	0.254
Piston rod	0.009	-0.0009	-0.00174	0.0534	-22.50	0.092	0.1369
Piston	0.005	-0.00085	-0.0031	0.05702	-22.50	0.1369	0.2435
Side wall	0.0061	-0.0004	0.0041	0.041	-45.01	0.068	0.1848

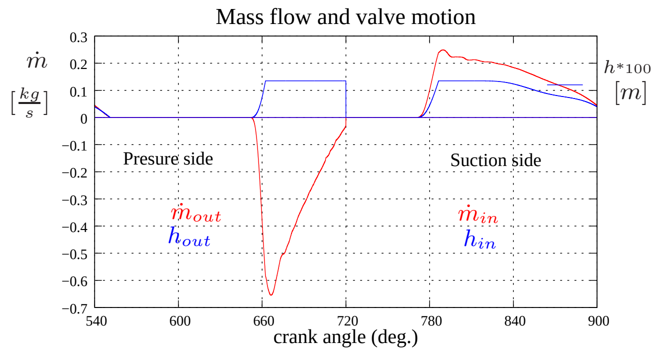
6.6.1 Heat transfer coefficient results

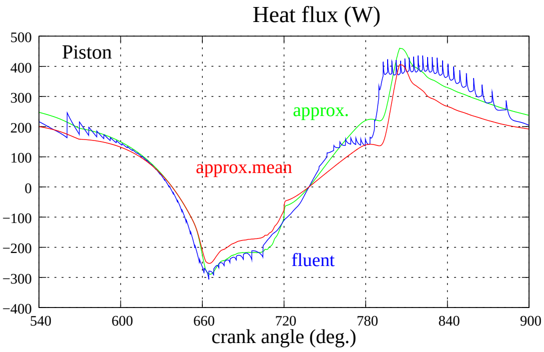


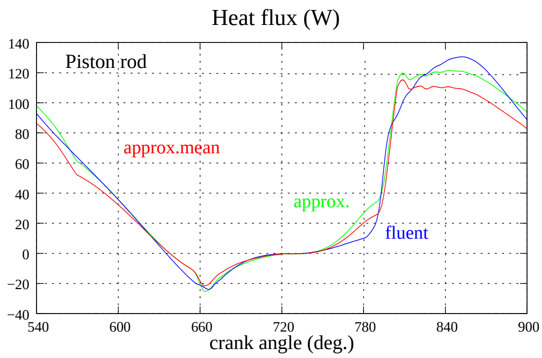
6.7 Case 7

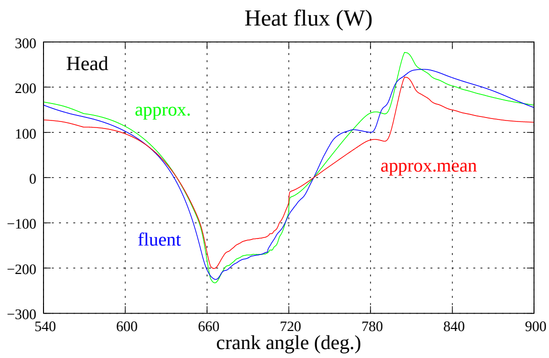
Values:

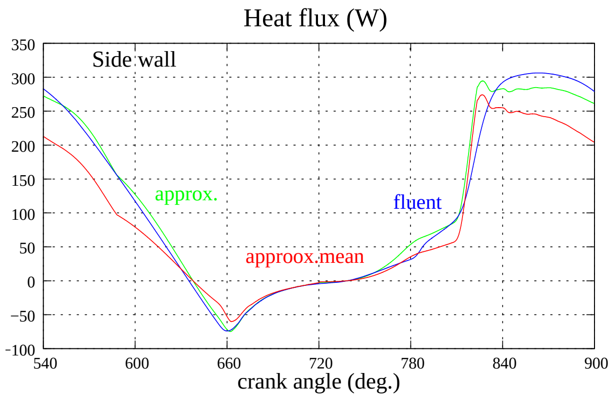
- Piston stroke: 90mm (standard value 90)
- Rod length: 250mm (standard value)
- Cra. speed: 1200 min^{-1} (standard value 980)
- Gas: air (standard value)
- $p_{in} = 1\text{bar}$, $p_{out} = 3\text{bar}$ (standard $p_{in} = 1$, $p_{out} = 5$)









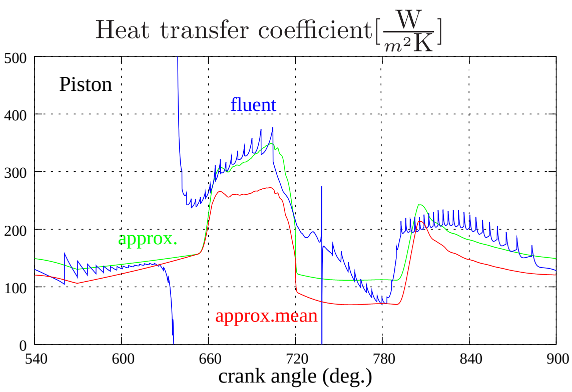


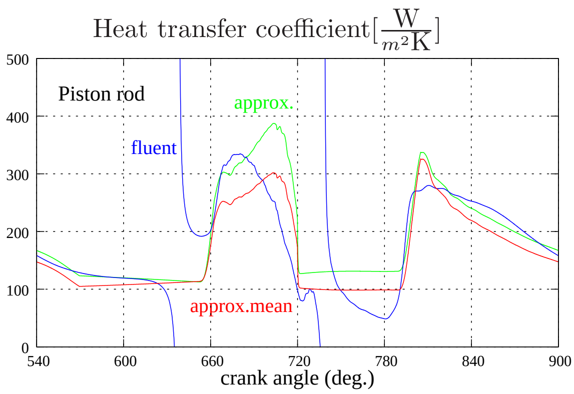
*The results valid for "half" of the compressor (axial symmetry)

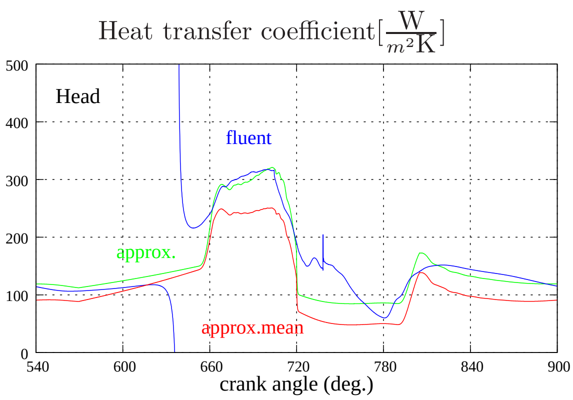
Tables of coefficients

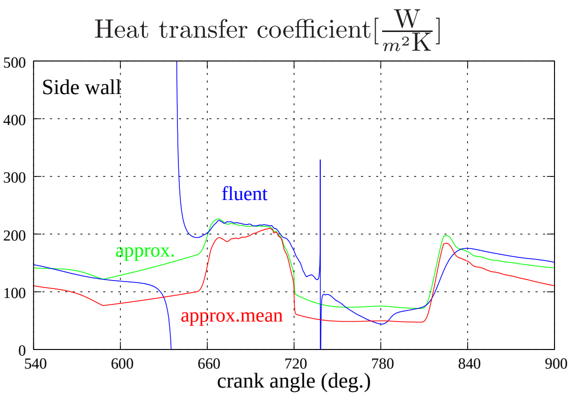
	St_{in}	St_{out}	St_k	Nu/Re	φ_0	error	error mean
Head	0.00331	-0.00089	-0.00268	0.04538	-18.53	0.1109	0.2655
Piston rod	0.00761	-0.00116	0.00077	0.0566	-18.53	0.0911	0.1372
Piston	0.00489	-0.00094	-0.001863	0.0551	-18.53	0.1484	0.2460
Side wall	0.00619	-0.000416	-0.003726	0.04317	-37.06	0.1034	0.2298

6.7.1 Heat transfer coefficient results





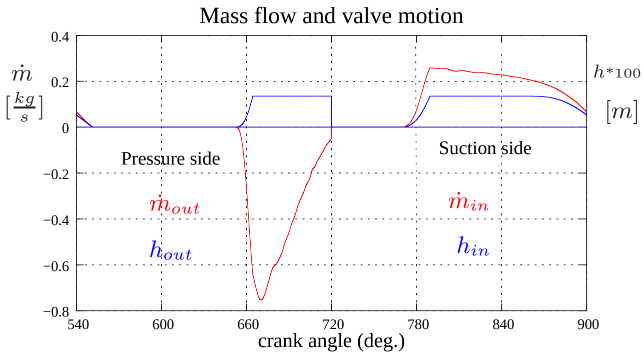


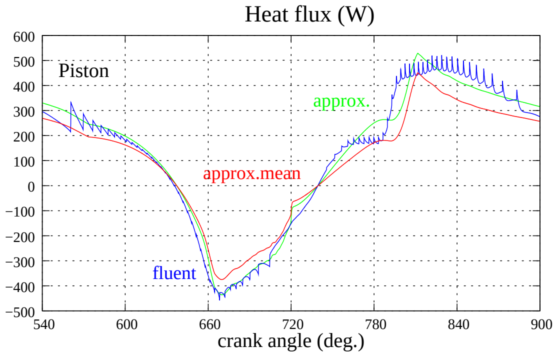


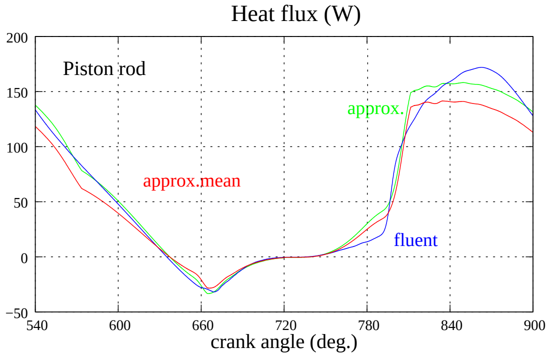
6.8 Case 8

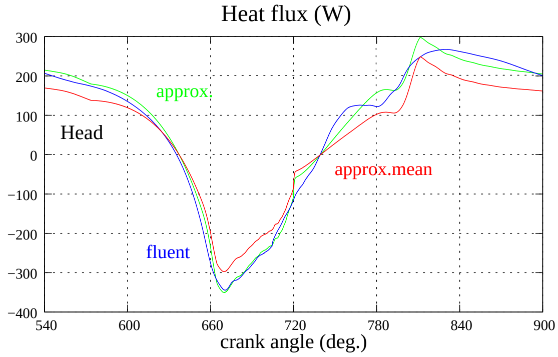
Values:

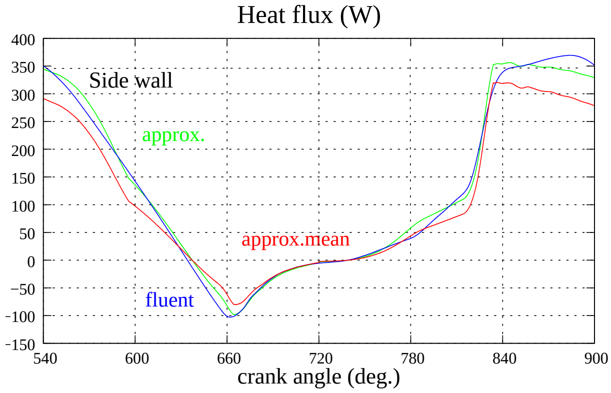
- Piston stroke: 90mm (standard value 90)
- Rod length: 250mm (standard value)
- Cra. speed: 1500 $\min^{-1}$ (standard value 980)
- Gas: air (standard value)
- $p_{in} = 1$bar, $p_{out} = 3$bar (standard $p_{in} = 1$, $p_{out} = 5$)









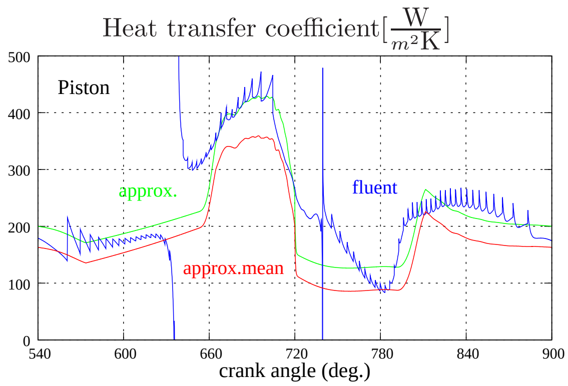


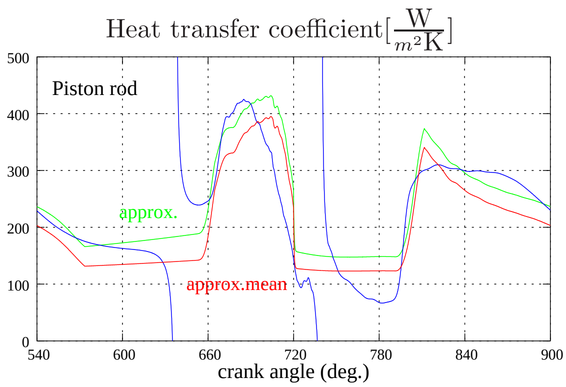
*The results valid for "half" of the compressor (axial symmetry)

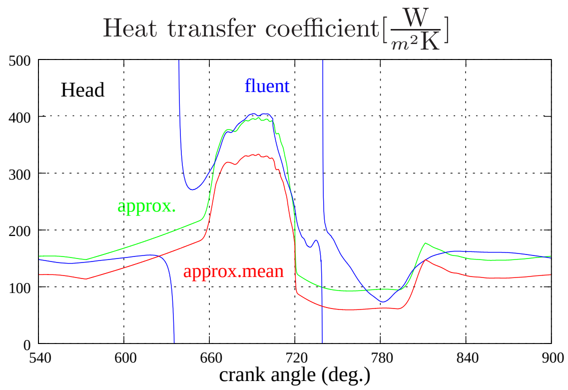
Tables of coefficients

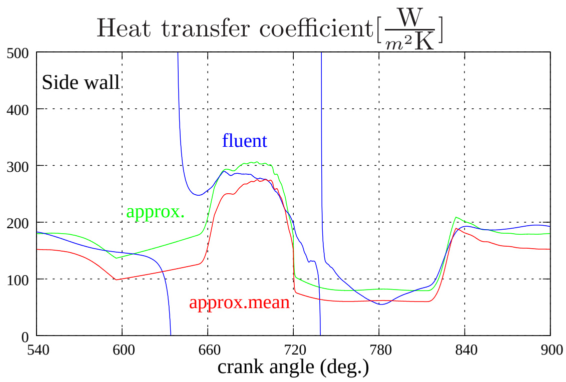
	St_{in}	St_{out}	St_k	Nu/Re	φ_0	error	error mean
Head	0.00328	-0.00078	-0.004	0.00446	-22.29	0.097	0.2262
Piston rod	0.00875	-0.000863	-0.00134	0.0566	-22.29	0.0954	0.1601
Piston	0.00537	-0.000826	-0.0032	0.0545	-22.29	0.1301	0.2275
Side wall	0.0067	-0.00057	-0.004	0.0446	-44.58	0.0683	0.1698

6.8.1 Heat transfer coefficient results





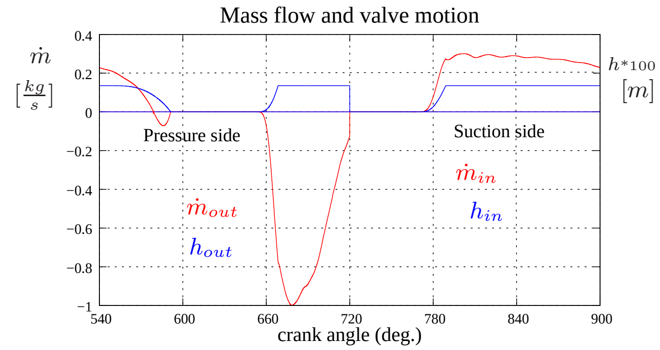


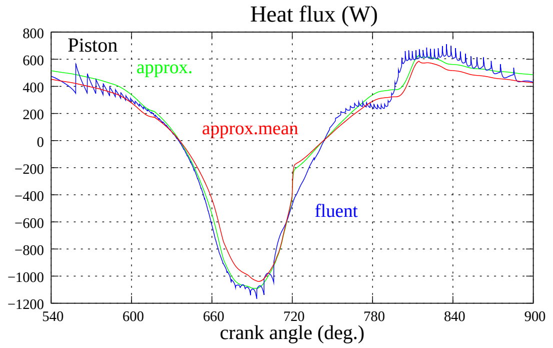


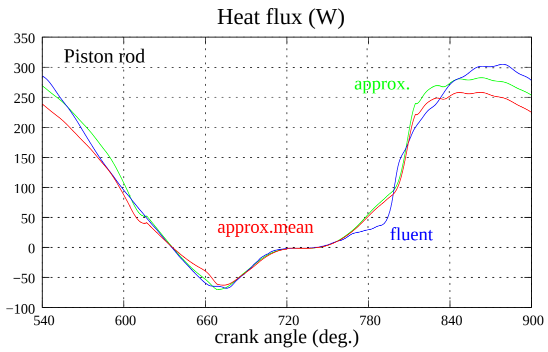
6.9 Case 9

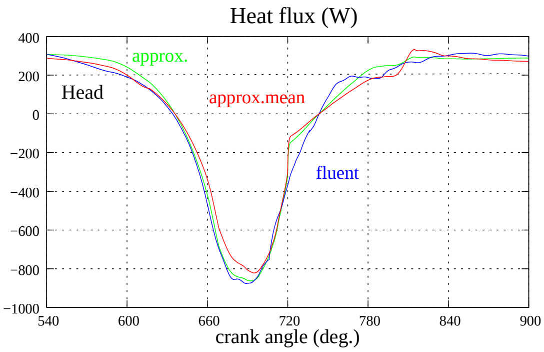
Values:

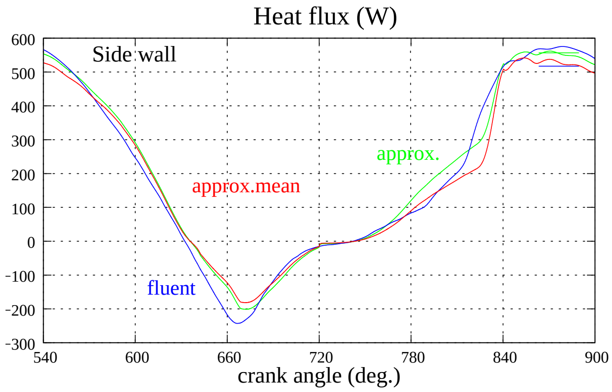
- Piston stroke: 110mm (standard value 90)
- Rod length: 250mm (standard value)
- Cra. speed: 2000 min^{-1} (standard value 980)
- Gas: air (standard value)
- p_{in} = 1bar, p_{out} = 3bar (standard $p_{in} = 1$, $p_{out} = 5$)









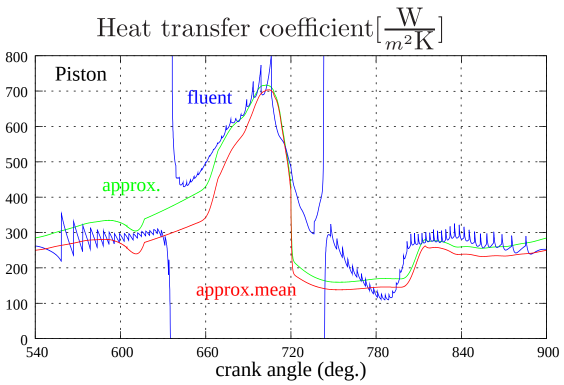


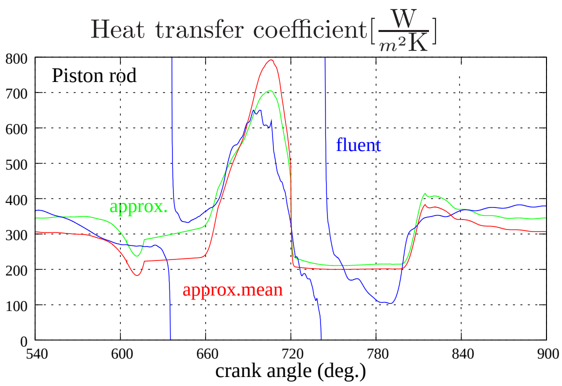
*The results valid for "half" of the compressor (axial symmetry)

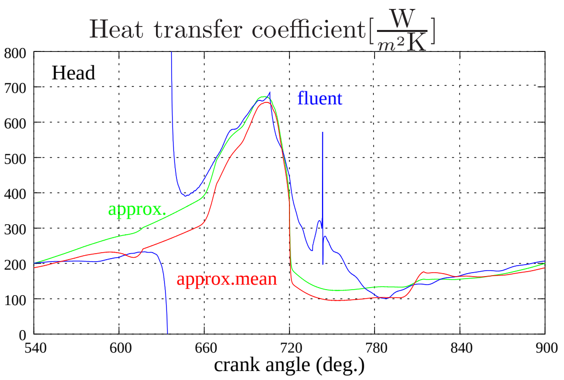
Tables of coefficients

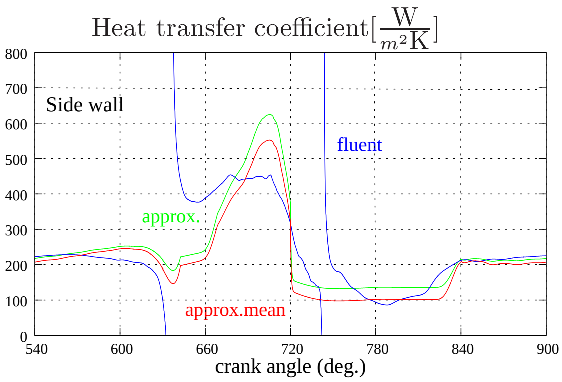
	St_{in}	St_{out}	St_k	Nu/Re	φ_0	error	error mean
Head	0.00108	-0.000628	-0.00479	0.041258	-25.65	0.1056	0.1463
Piston rod	0.00929	-0.00066	-0.001986	0.05215	-25.65	0.0998	0.1449
Piston	0.0052	-0.0006398	-0.00482	0.049214	-25.65	0.1163	0.1571
Side wall	0.00495	-0.00066	-0.0019	0.03461	-51.30	0.1012	0.1303

6.9.1 Heat transfer coefficient results





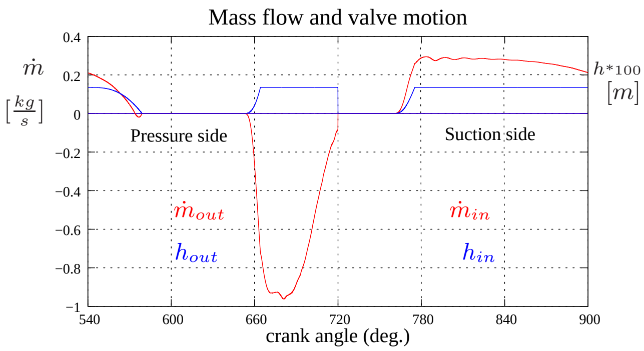


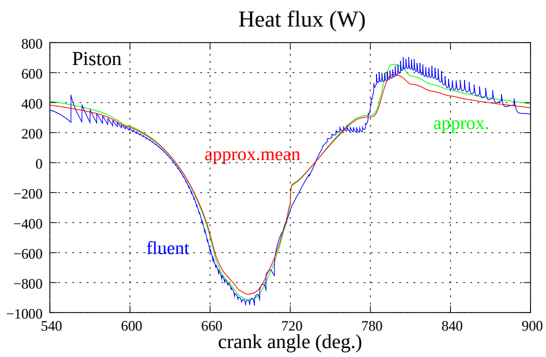


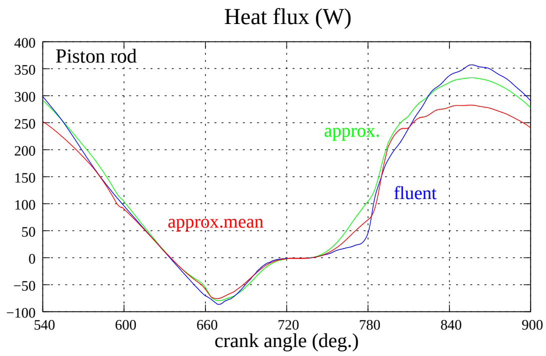
6.10 Case 10

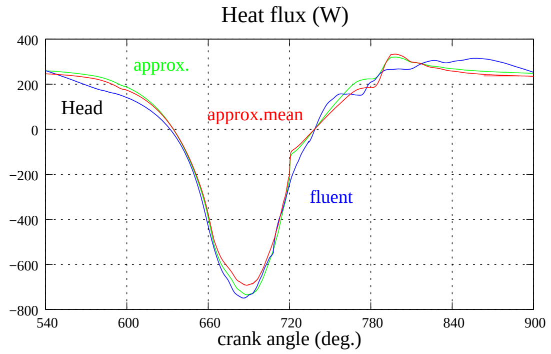
Values:

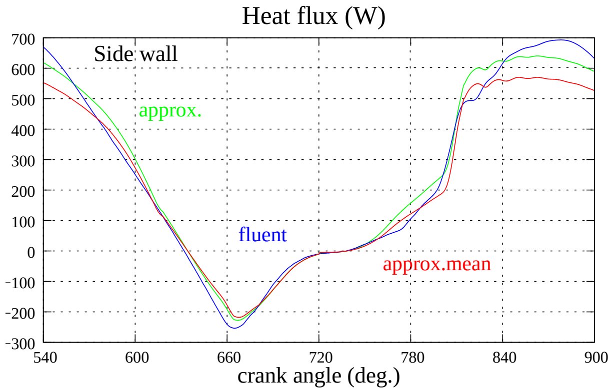
- Piston stroke: 140mm (standard value 90)
- Rod length: 250mm (standard value)
- Cra. speed: 1500 $\min^{-1}$ (standard value 980)
- Gas: air (standard value)
- p_{in} = 1bar, p_{out} = 3bar (standard $p_{in} = 1$, $p_{out} = 5$)









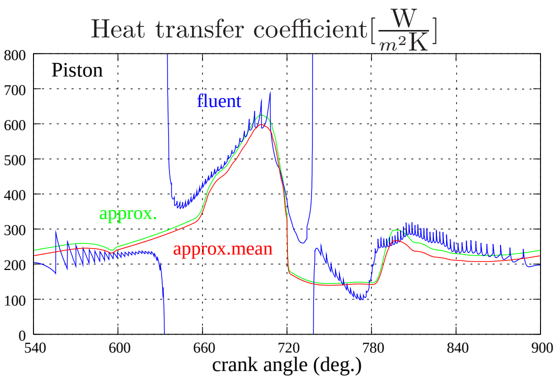


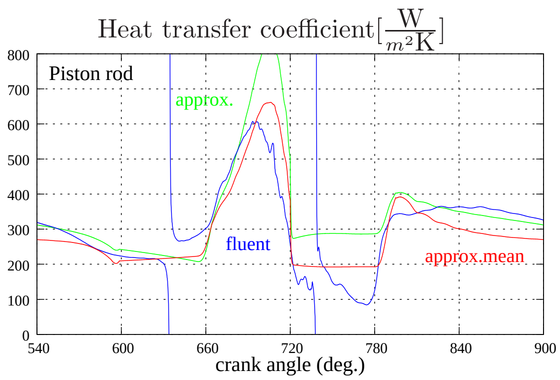
*The results valid for "half" of the compressor (axial symmetry)

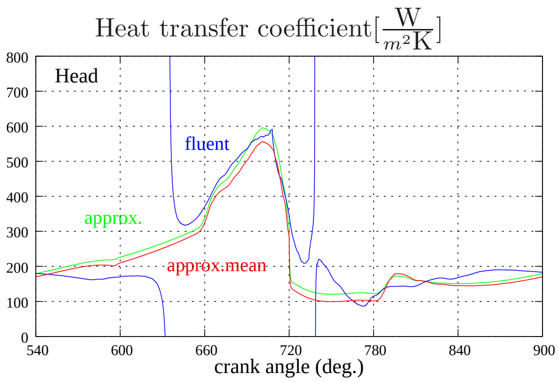
Tables of coefficients

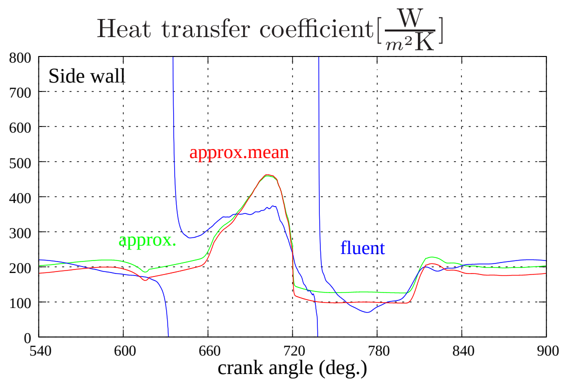
	St_{in}	St_{out}	St_k	Nu/Re	φ_0	error	error mean
Head	0.002239	-0.000726	-0.00376	0.03695	-19.61	0.1116	0.1276
Piston rod	0.00489	-0.001089	0.0016322	0.06231	-19.61	0.094	0.1637
Piston	0.0065	-0.000739	-0.00374	0.04247	-19.61	0.1116	0.1280
Side wall	0.0061	-0.00054	-0.00194	0.03388	-39.23	0.0974	0.1447

6.10.1 Heat transfer coefficient results





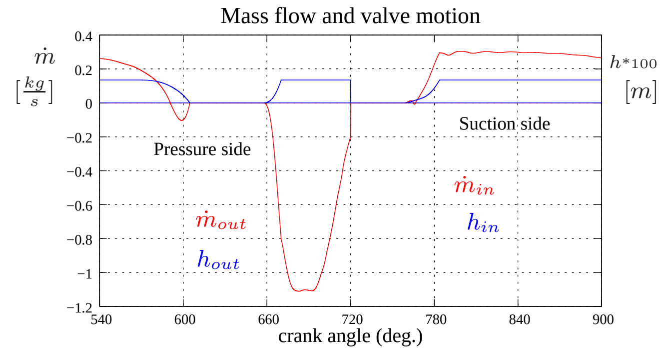


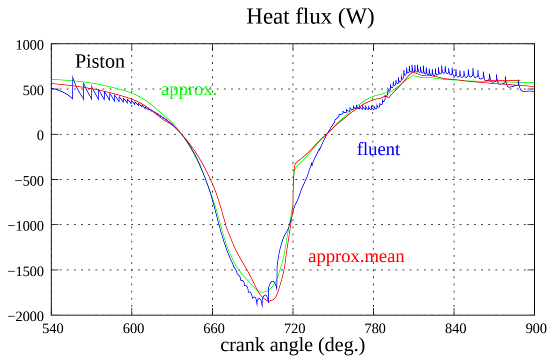


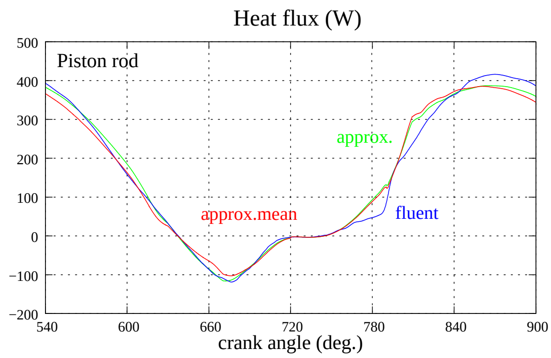
6.11 Case 11

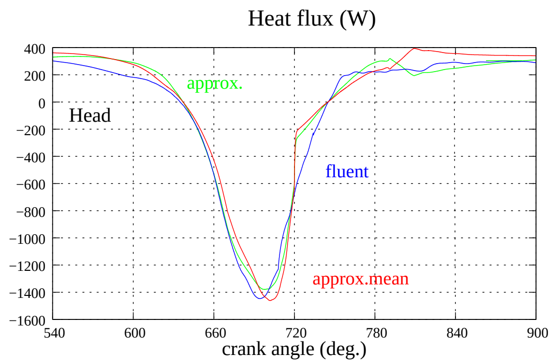
Values:

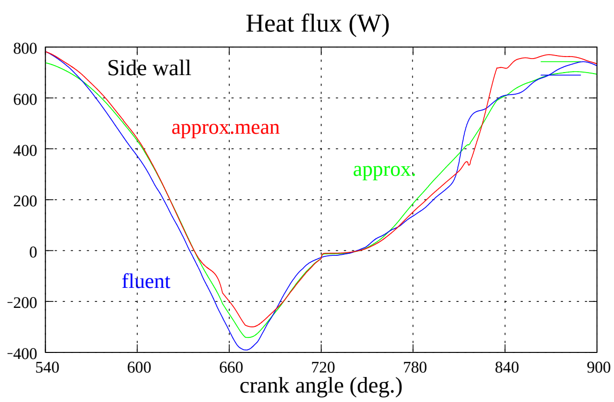
- Piston stroke: 140mm (standard value 90)
- Rod length: 250mm (standard value)
- Cra. speed: 2000 min^{-1} (standard value 980)
- Gas: air (standard value)
- p_{in} = 1bar, p_{out} = 3bar (standard $p_{in} = 1$, $p_{out} = 5$)









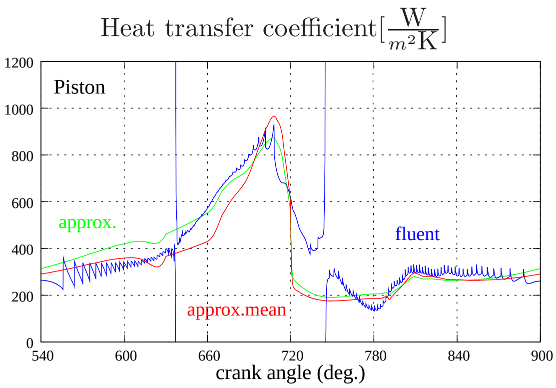


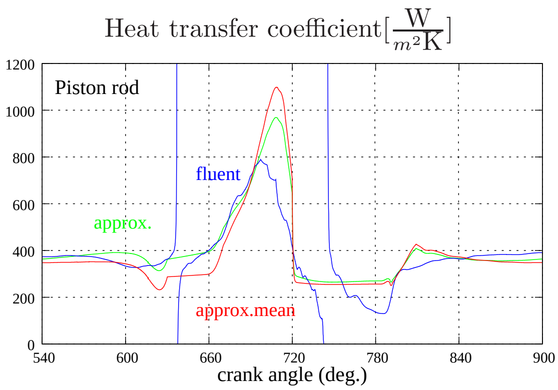
*The results valid for "half" of the compressor (axial symmetry)

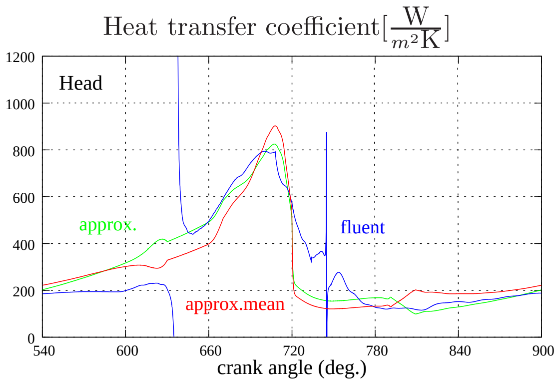
Tables of coefficients

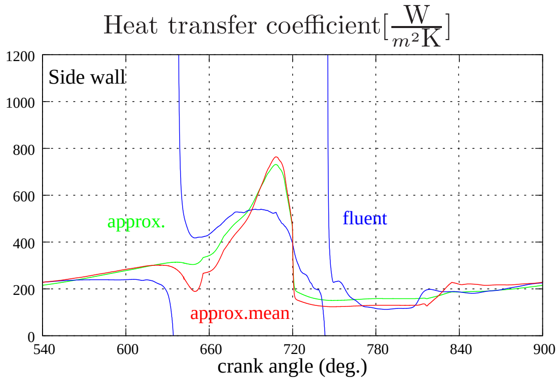
	St_{in}	St_{out}	St_k	Nu/Re	φ_0	error	error mean
Head	-0.0034	-0.000054	-0.00479	0.0408	-25.47	0.1447	0.2004
Piston rod	0.00684	-0.000672	-0.001849	0.051185	-25.47	0.0845	0.1002
Piston	0.003659	-0.000538	-0.005125	0.048	-25.47	0.1336	0.1645
Side wall	0.00181	-0.000514	-0.00271	0.034	-50.94	0.0952	0.1428

6.11.1 Heat transfer coefficient results





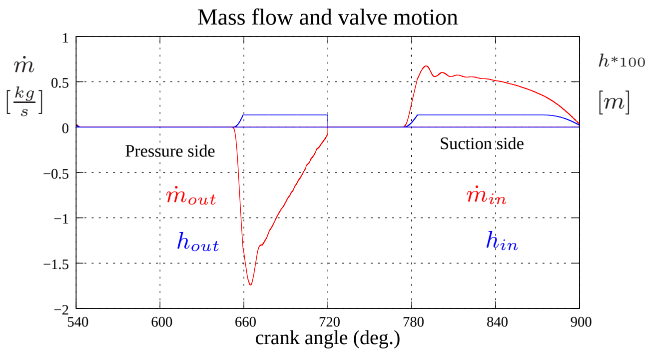


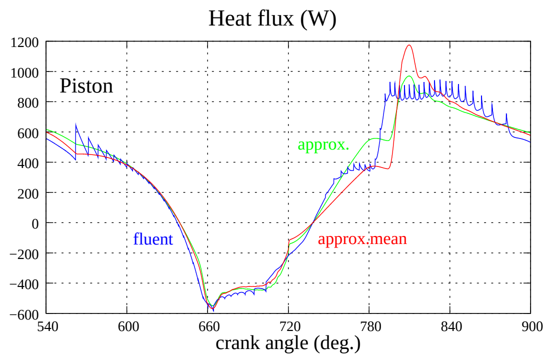


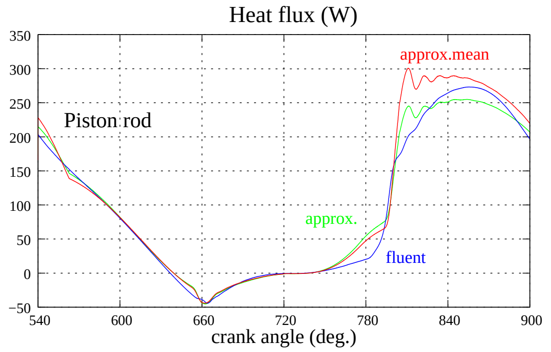
6.12 Case 12

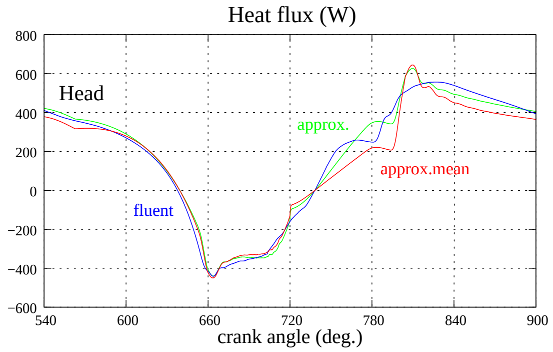
Values:

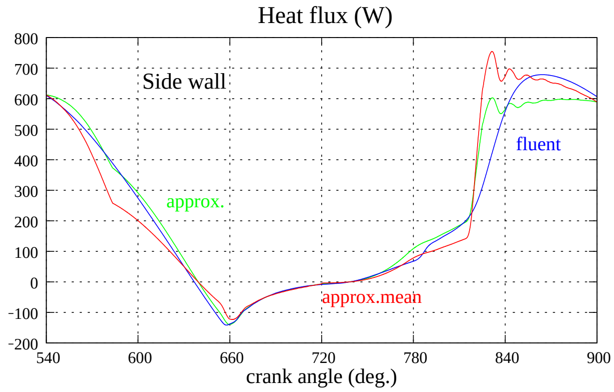
- Piston stroke: 80mm (standard value 90)
- Rod length: 250mm (standard value)
- Cra. speed: 1200 min^{-1} (standard value 980)
- Gas: air (standard value)
- $p_{in} = 3$bar, $p_{out} = 9$bar (standard $p_{in} = 1$, $p_{out} = 5$)









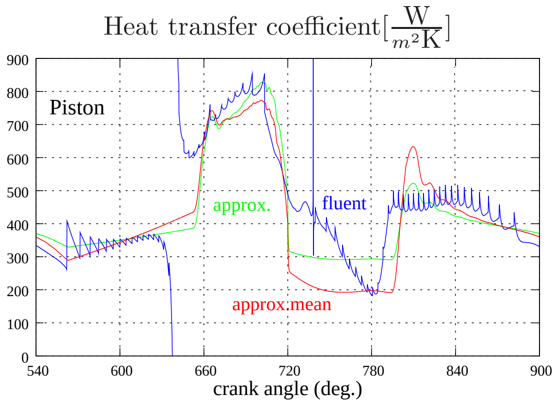


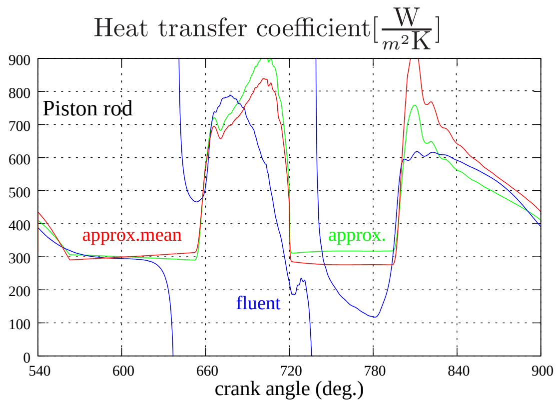
*The results valid for "half" of the compressor (axial symmetry)

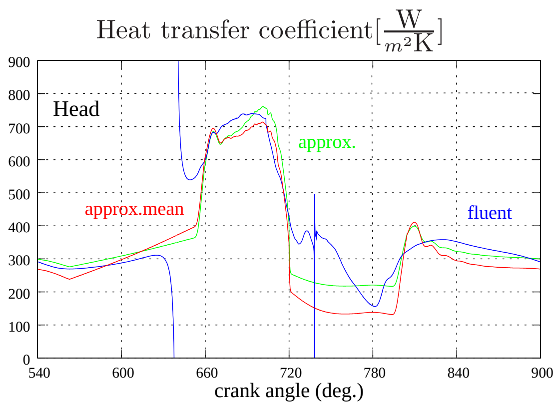
Tables of coefficients

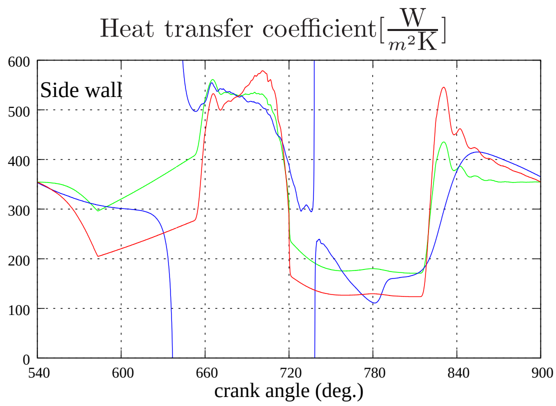
	St_{in}	St_{out}	St_k	Nu/Re	φ_0	error	error mean
Head	-0.0024	0.00073	0.0023	-0.035	-20.53	0.1026	0.198
Piston rod	-0.00116	0.00019	-0.00043	-0.0427	-20.5347	0.0918	0.1416
Piston	-0.0003	0.000076	0.00148	-0.0437	-20.534	0.142	0.2
Side wall	-0.00448	0.00037	0.0036	-0.0328	-41.069	0.132	0.2003

6.12.1 Heat transfer coefficient results





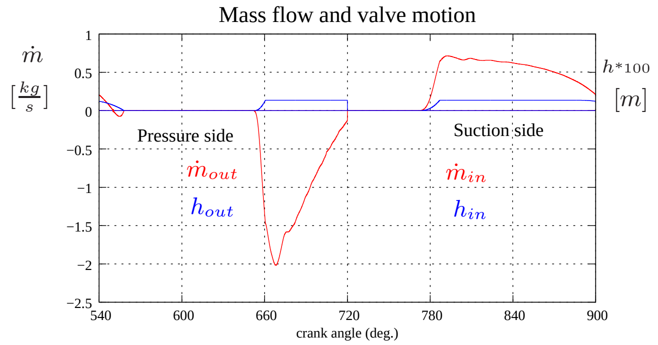


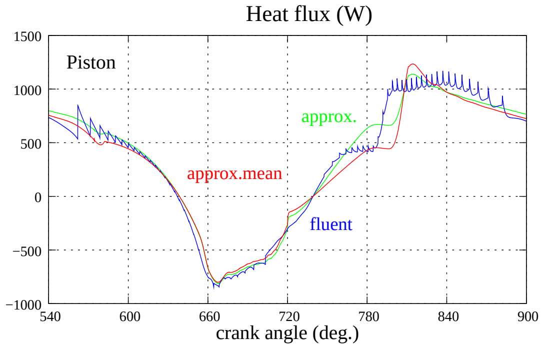


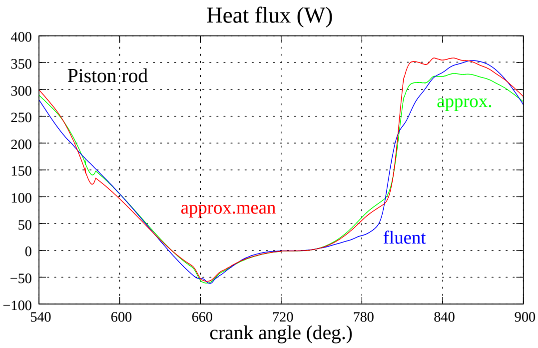
6.13 Case 13

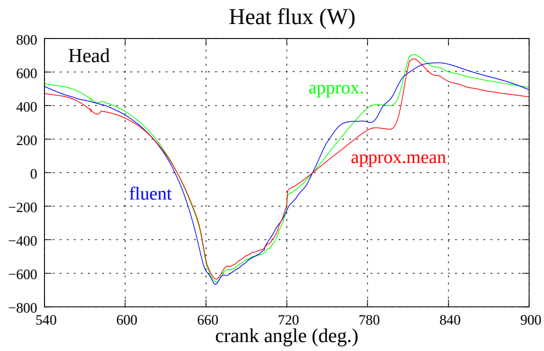
Values:

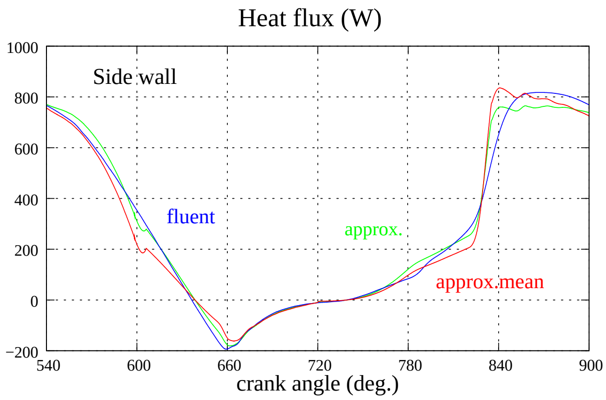
- Piston stroke: 80mm (standard value 90)
- Rod length: 250mm (standard value)
- Cra. speed: 1500 min^{-1} (standard value 980)
- Gas: air (standard value)
- $p_{in} = 3\text{bar}, \quad p_{out} = 9\text{bar}$ (standard $p_{in} = 1, \quad p_{out} = 5$)









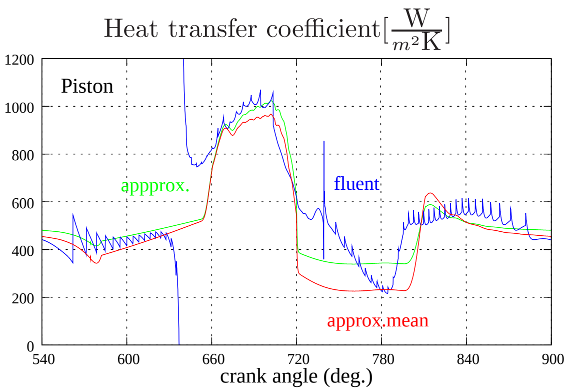


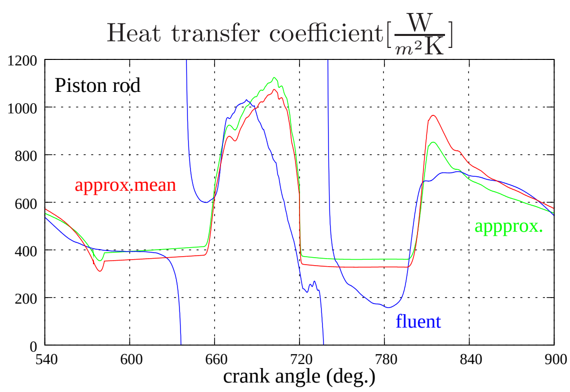
*The results valid for “half” of the compressor (axial symmetry)

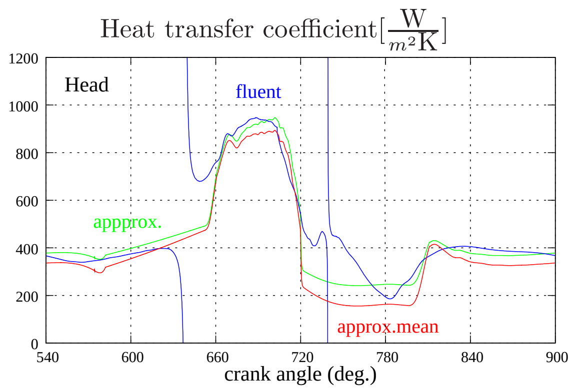
Tables of coefficients

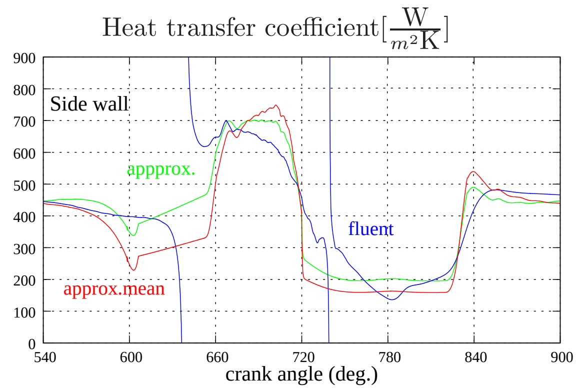
	St_{in}	St_{out}	St_k	Nu/Re	φ_0	error	error mean
Head	0.0025	-0.00069	-0.0031	0.0415	-24.13	0.096	0.1636
Piston rod	0.0065	-0.00088	-0.000663	0.0503	-24.13	0.096	0.1251
Piston	0.00329	-0.0007	-0.002317	0.05237	-24.13	0.1342	0.1786
Side wall	0.00511	-0.00043	-0.00332	0.0361	-48.25	0.08	0.1196

6.13.1 Heat transfer coefficient results





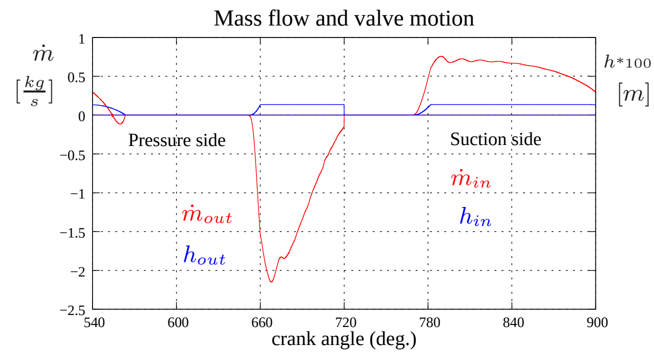


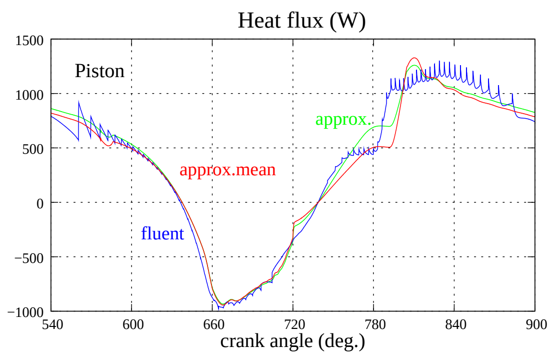


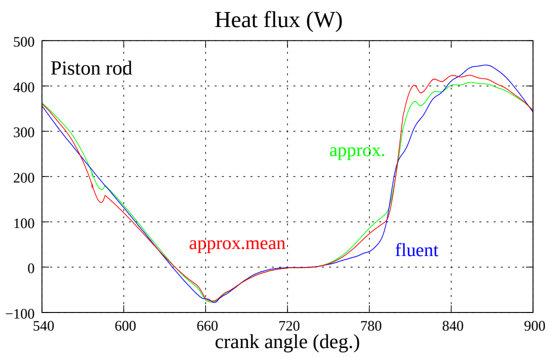
6.14 Case 14

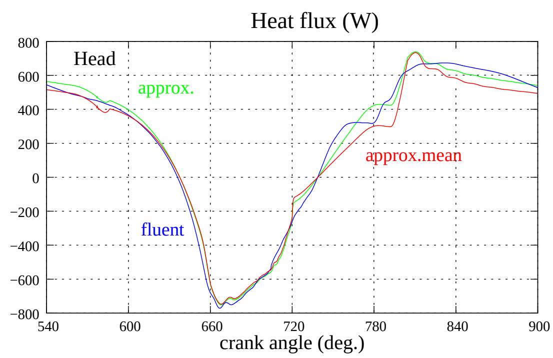
Values:

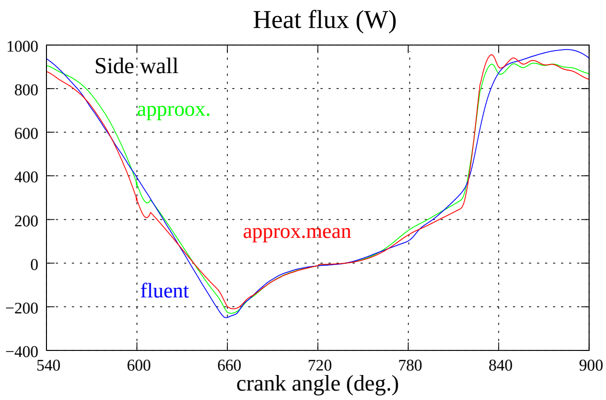
- Piston stroke: 90mm (standard value 90)
- Rod length: 250mm (standard value)
- Cra. speed: 1500 min^{-1} (standard value 980)
- Gas: air (standard value)
- $p_{in} = 3$bar, $p_{out} = 9$bar (standard $p_{in} = 1$, $p_{out} = 5$)









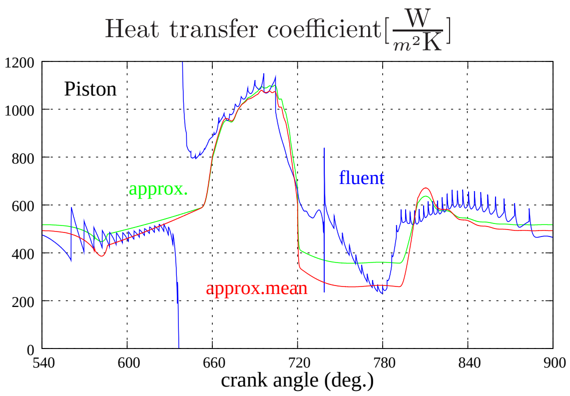


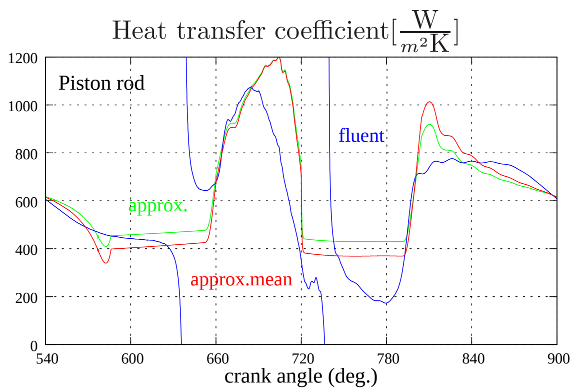
*The results valid for “half” of the compressor (axial symmetry)

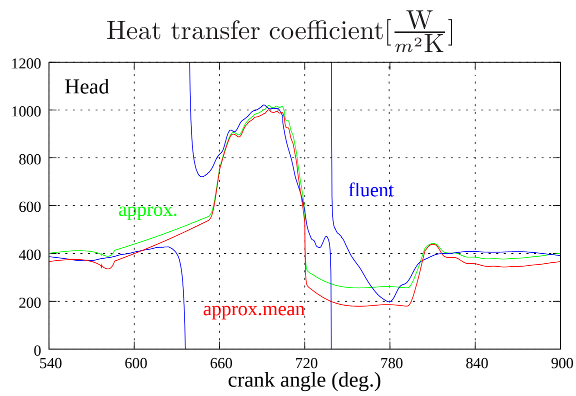
Tables of coefficients

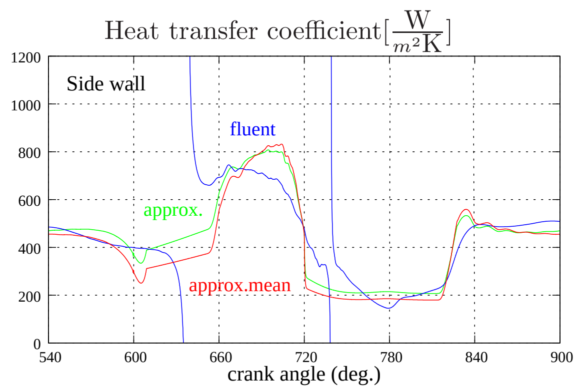
	St_{in}	St_{out}	St_k	Nu/Re	φ_0	error	error mean
Head	0.00246	-0.000658	-0.003271	0.03979	-22.81	0.0909	0.1357
Piston rod	0.006389	-0.000798	-0.000512	0.05277	-22.81	0.095	0.1109
Piston	0.003687	-0.000676	-0.00254	0.0497	-22.81	0.1282	0.1552
Side wall	0.00572	-0.00049	-0.00291	0.0332	-45.61	0.0827	0.1018

6.14.1 Heat transfer coefficient results





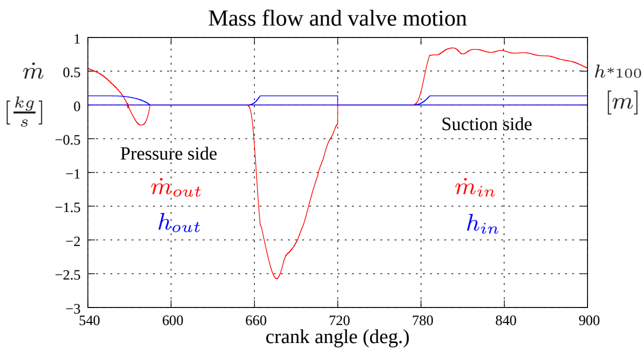


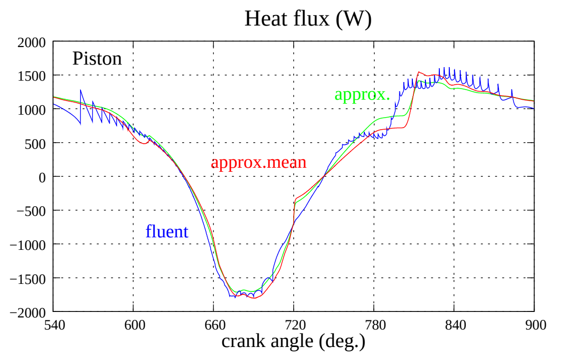


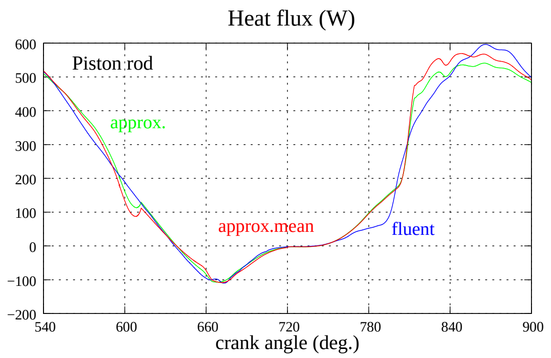
6.15 Case 15

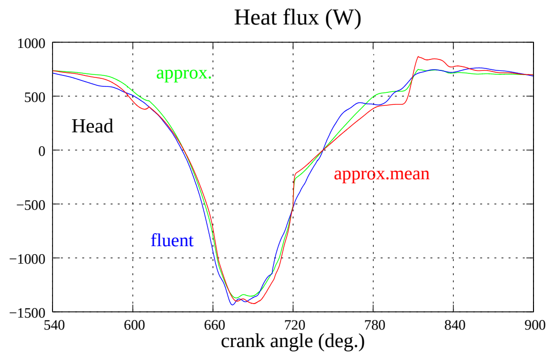
Values:

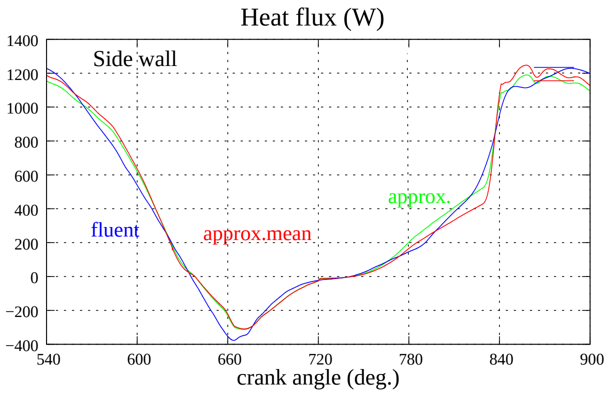
- Piston stroke: 90mm (standard value 90)
- Rod length: 250mm (standard value)
- Cra. speed: 2000 $\min^{-1}$ (standard value 980)
- Gas: air (standard value)
- $p_{in} = 3$bar, $p_{out} = 9$bar (standard $p_{in} = 1$, $p_{out} = 5$)









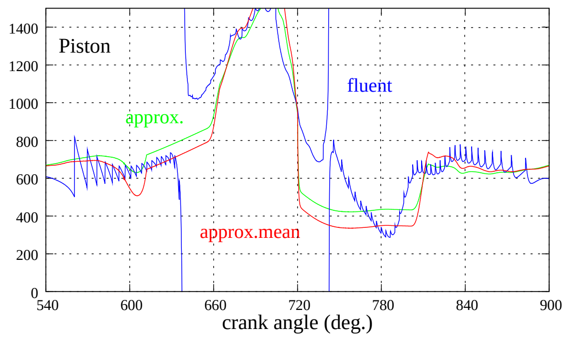


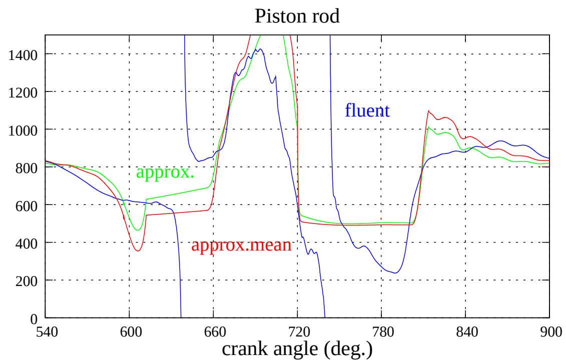
*The results valid for "half" of the compressor (axial symmetry)

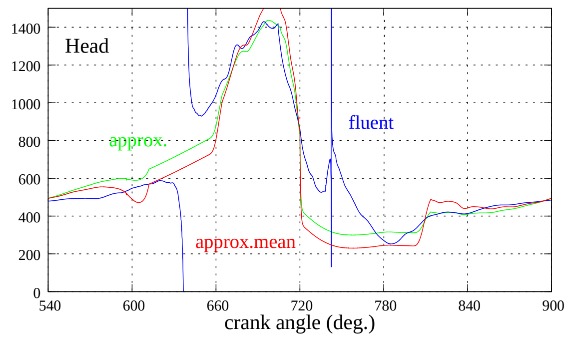
Tables of coefficients

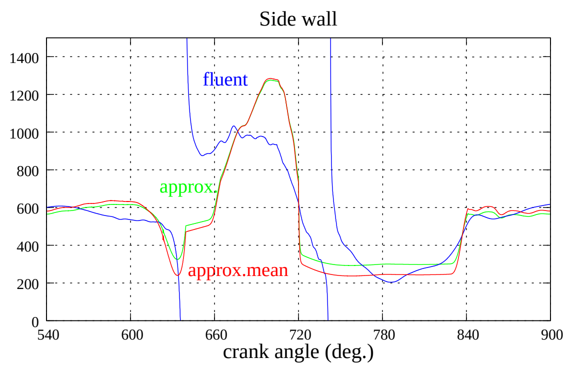
	St_{in}	St_{out}	St_k	Nu/Re	φ_0	error	error mean
Head	0.001524	-0.000561	-0.004049	0.039041	-27.37	0.0934	0.1272
Piston rod	0.00707	-0.000637	-0.001507	0.049199	-27.37	0.0979	0.1121
Piston	0.003375	-0.000572	-0.0035	0.0484	-27.37	0.1215	0.1430
Side wall	0.0051	-0.00056	-0.0019	0.03195	-54.73	0.0806	0.0975

6.15.1 Heat transfer coefficient results





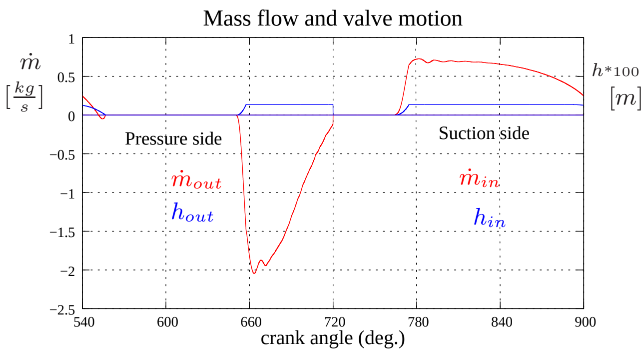


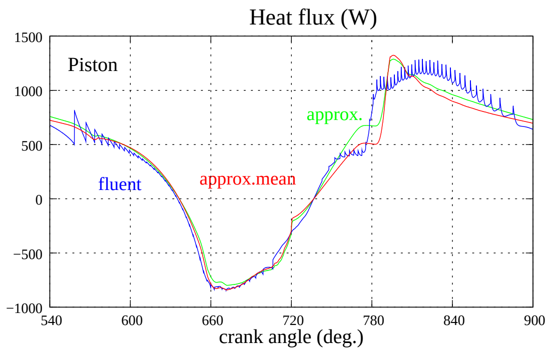


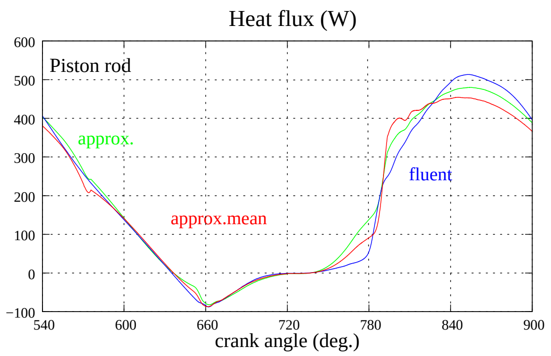
6.16 Case 16

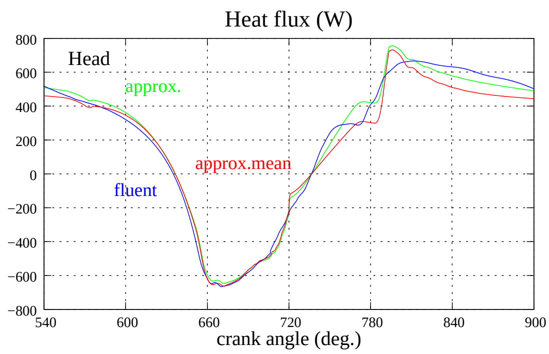
Values:

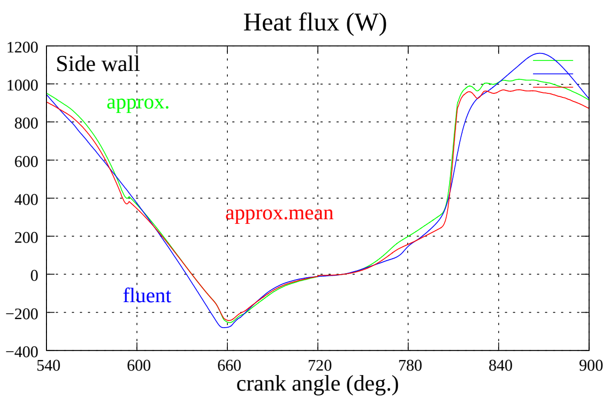
- Piston stroke: 110mm (standard value 90)
- Rod length: 250mm (standard value)
- Cra. speed: 1200 min^{-1} (standard value 980)
- Gas: air (standard value)
- $p_{in} = 3\text{bar}$, $p_{out} = 9\text{bar}$ (standard $p_{in} = 1$, $p_{out} = 5$)









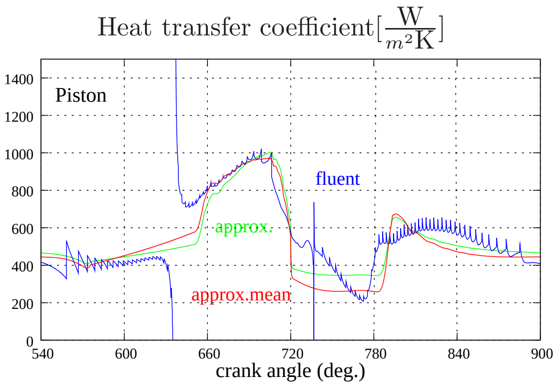


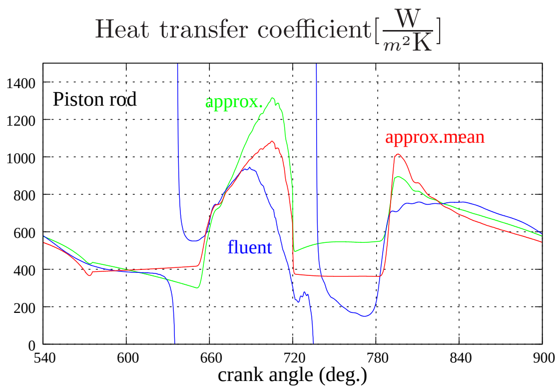
*The results valid for "half" of the compressor (axial symmetry)

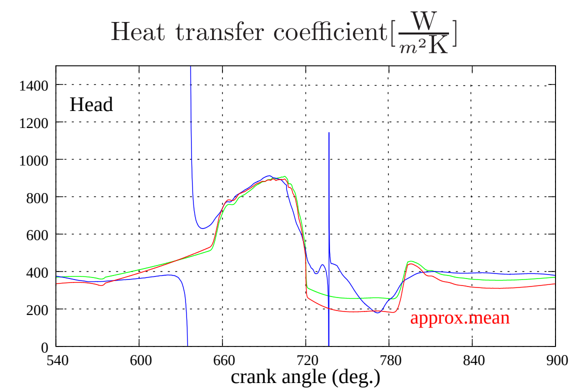
Tables of coefficients

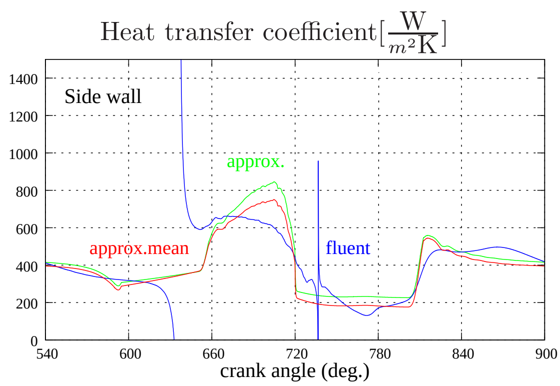
	St_{in}	St_{out}	St_k	Nu/Re	φ_0	error	error mean
Head	0.0027	-0.00066	-0.0029	0.03864	-19.06	0.097	0.1429
Piston rod	0.00438	-0.001078	0.00281	0.0597	-19.06	0.0941	0.1201
Piston	0.004043	-0.0007181	-0.00188	0.04699	-19.06	0.1389	0.1605
Side wall	0.006062	-0.000682	-0.001542	0.0321	-38.13	0.1082	0.1223

6.16.1 Heat transfer coefficient results





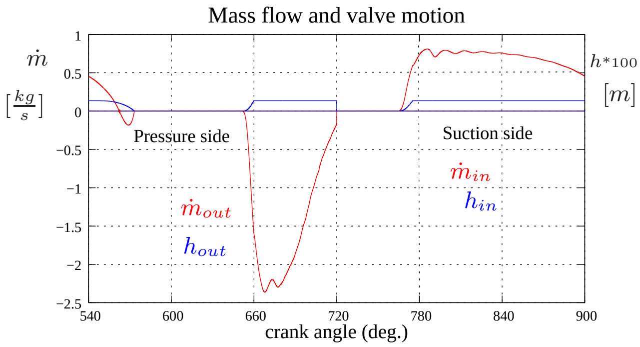


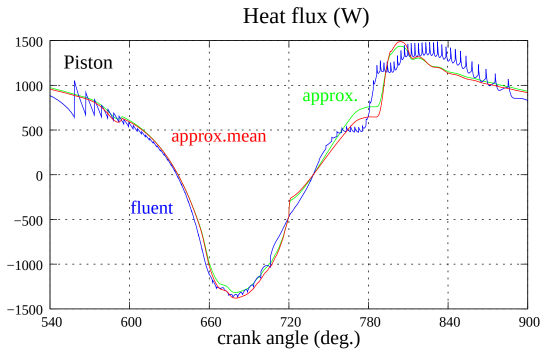


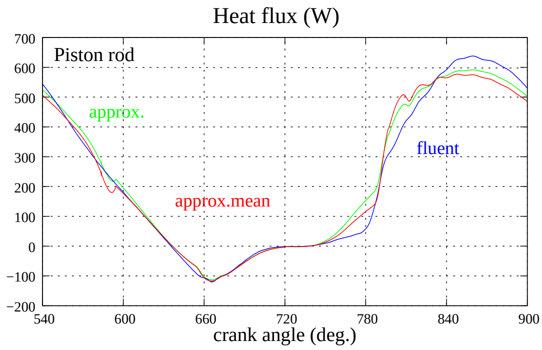
6.17 Case 17

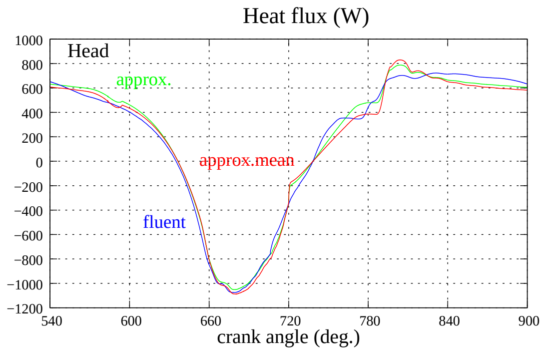
Values:

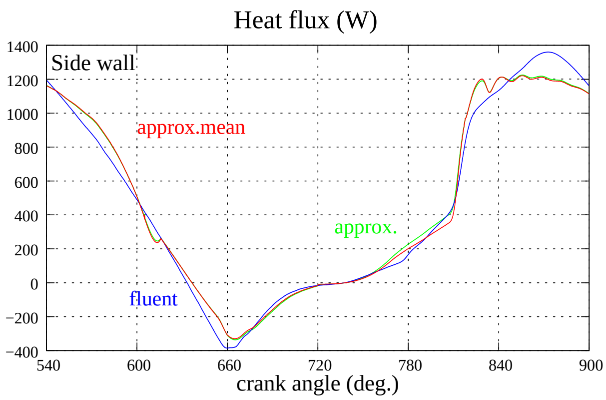
- Piston stroke: 110mm (standard value 90)
- Rod length: 250mm (standard value)
- Cra. speed: 1500 min^{-1} (standard value 980)
- Gas: air (standard value)
- p_{in} = 3bar, p_{out} = 9bar (standard p_{in} = 1, p_{out} = 5)









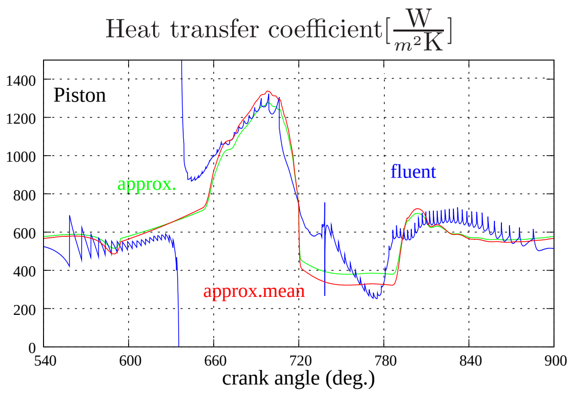


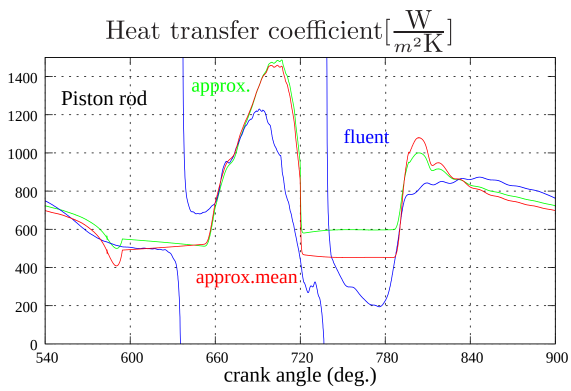
*The results valid for "half" of the compressor (axial symmetry)

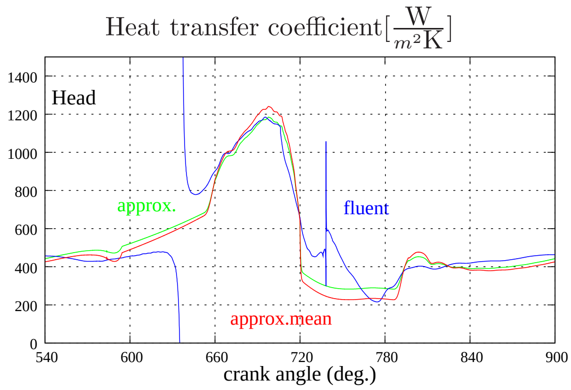
Tables of coefficients

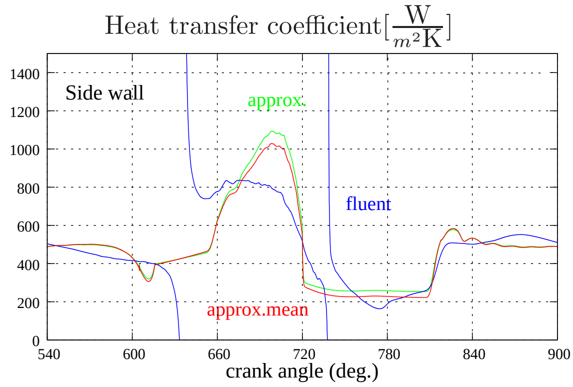
	St_{in}	St_{out}	St_k	Nu/Re	φ_0	error	error mean
Head	0.00235	-0.0006	-0.0035681	0.03698	-21.37	0.0875	0.1047
Piston rod	0.005371	-0.000816	0.000772	0.056383	-21.37	0.0971	0.1097
Piston	0.00432	-0.000633	-0.00298	0.04489	-21.37	0.1195	0.1278
Side wall	0.006031	-0.00064	-0.00357	0.03699	-42.74	0.0942	0.0961

6.17.1 Heat transfer coefficient results





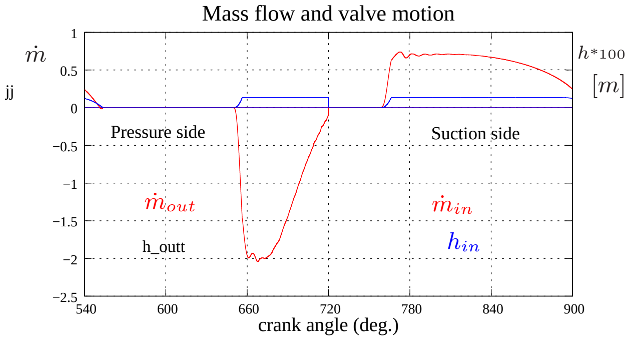


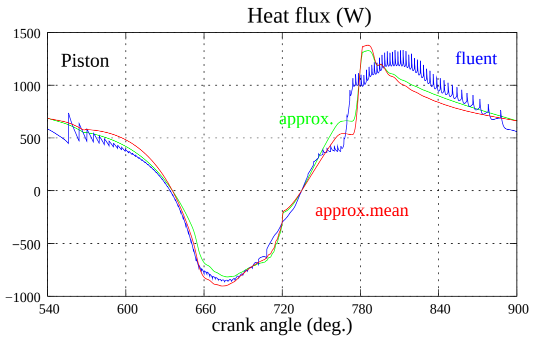


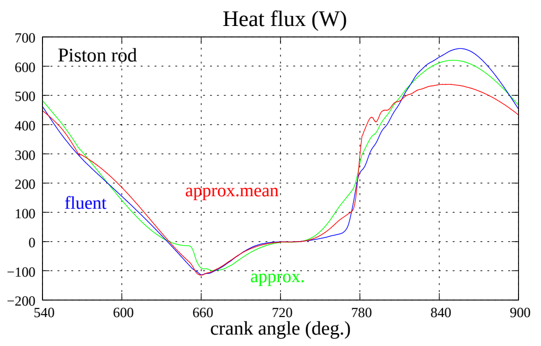
6.18 Case 18

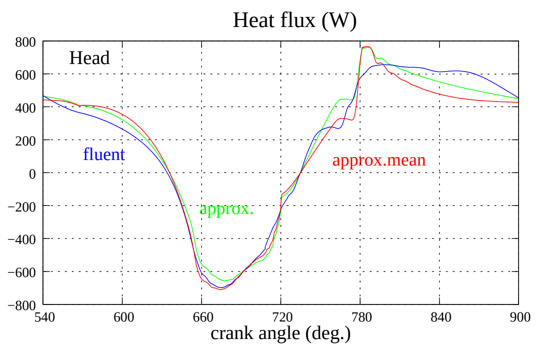
Values:

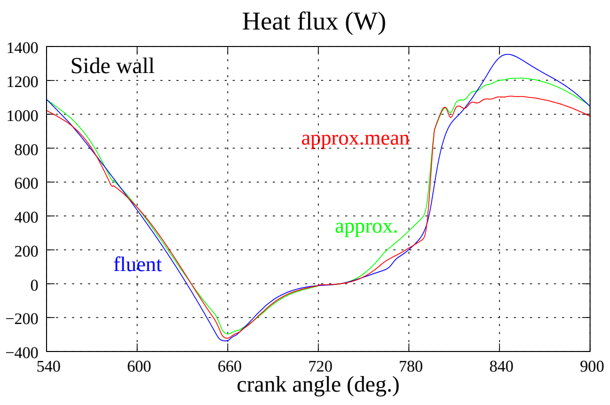
- Piston stroke: 140mm (standard value 90)
- Rod length: 250mm (standard value)
- Cra. speed: 980 min^{-1} (standard value 980)
- Gas: air (standard value)
- $p_{in} = 3$bar, $p_{out} = 9$bar (standard $p_{in} = 1$, $p_{out} = 5$)









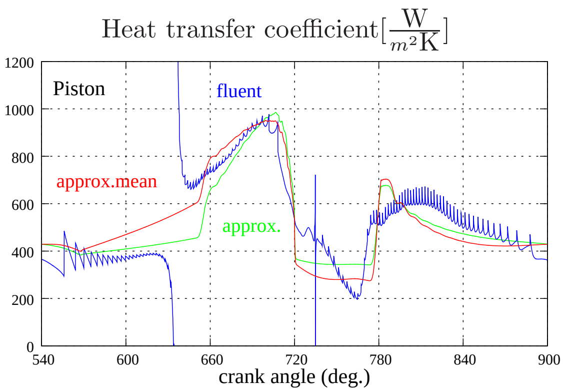


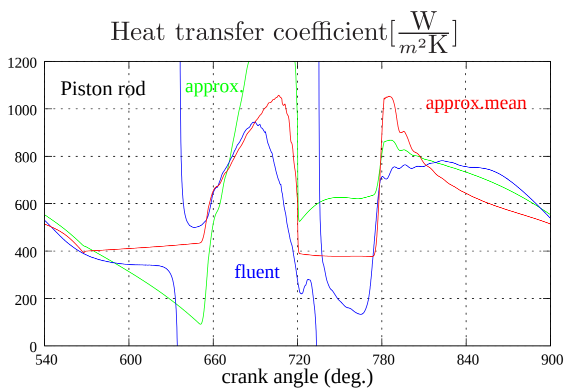
*The results valid for "half" of the compressor (axial symmetry)

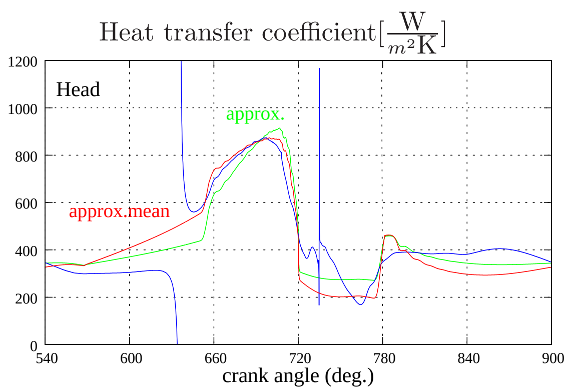
Tables of coefficients

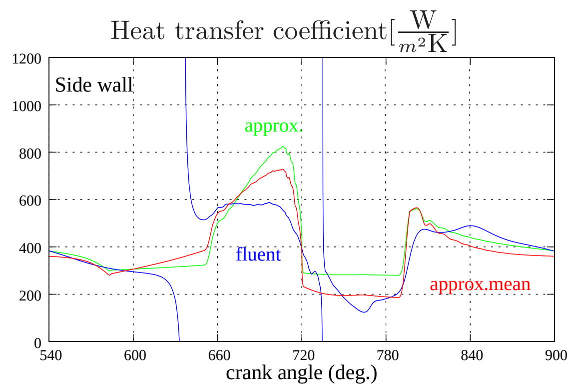
	St_{in}	St_{out}	St_k	Nu/Re	φ_0	error	error mean
Head	0.00239	-0.00075	-0.00183	0.0363	-15.35	0.1291	0.1697
Piston rod	0.00272	-0.00170		0.00595	-15.35	0.0925	0.1529
Piston	0.00421	-0.000779	-0.001249	0.04314	-15.35	0.1455	0.1677
Side wall	0.00494	-0.000687	-0.0004586	0.034156	-30.70	0.1006	0.1273

6.18.1 Heat transfer coefficient results





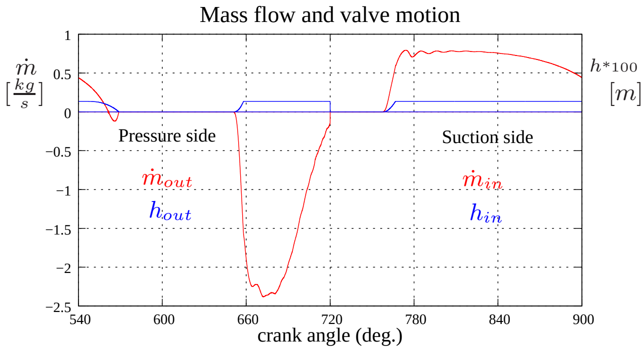


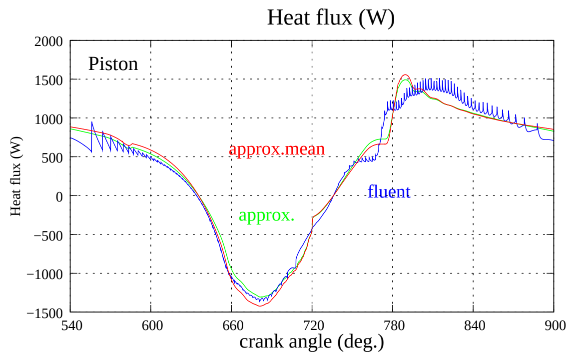


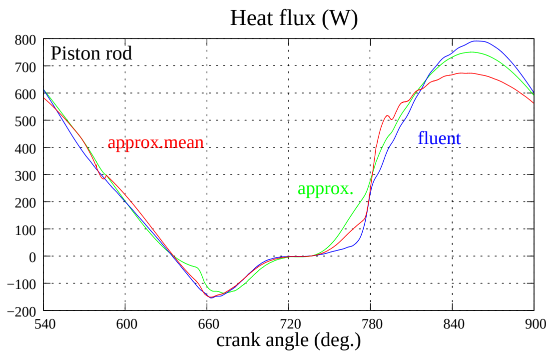
6.19 Case 19

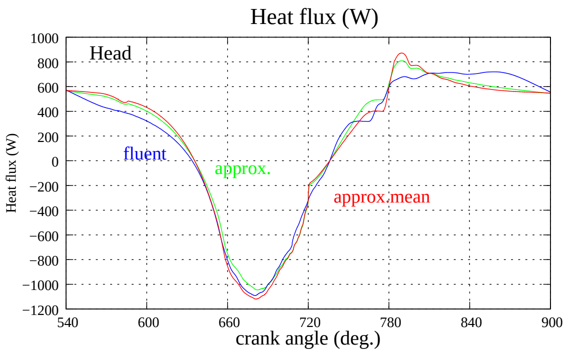
Values:

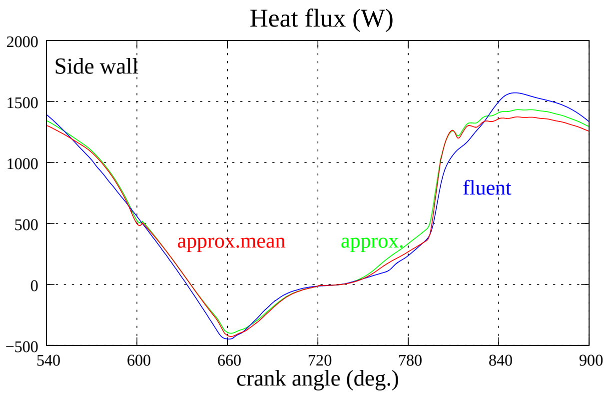
- Piston stroke: 140mm (standard value 90)
- Rod length: 250mm (standard value)
- Cra. speed: 1200 min^{-1} (standard value 980)
- Gas: air (standard value)
- $p_{in} = 3$bar, $p_{out} = 9$bar (standard $p_{in} = 1$, $p_{out} = 5$)









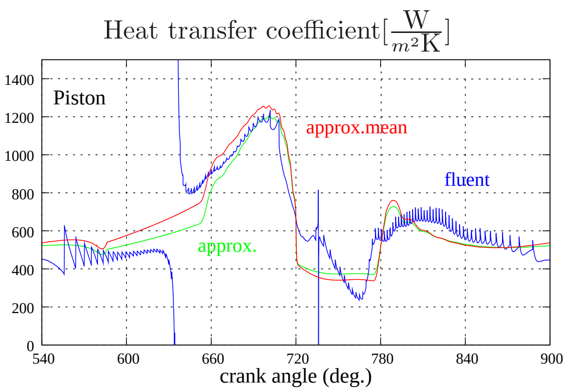


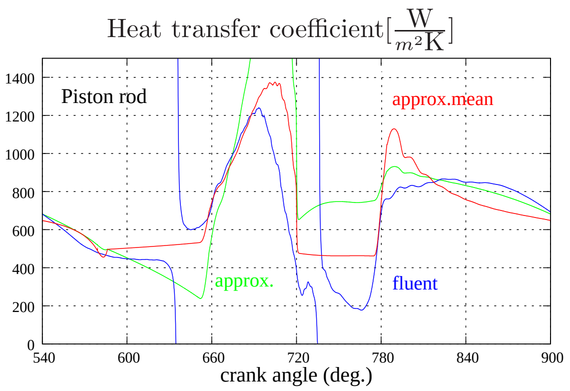
*The results valid for "half" of the compressor (axial symmetry)

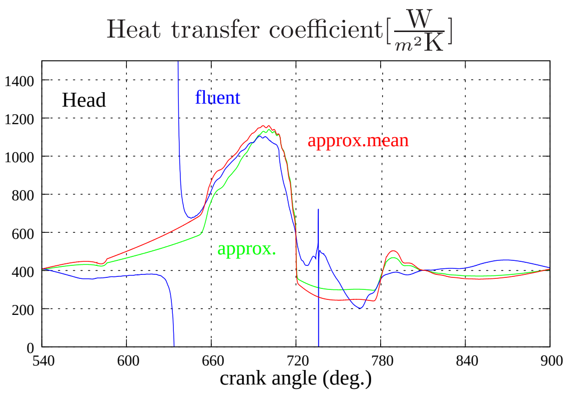
Tables of coefficients

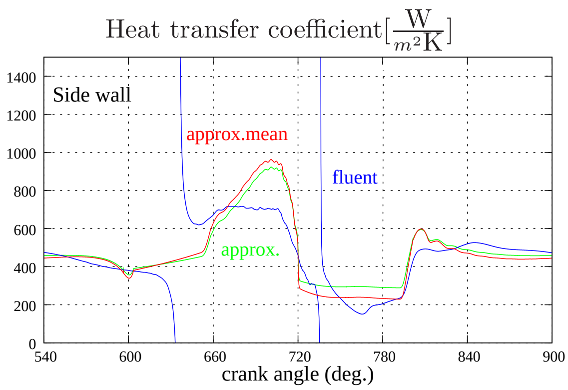
	St_{in}	St_{out}	St_k	Nu/Re	φ_0	error	error mean
Head	0.00223	-0.00068	-0.00256	0.03458	-17.40	0.1205	0.1398
Piston rod	0.0021	-0.00142	0.004539	0.06131	-17.40	0.0898	0.1303
Piston	0.00457	-0.000688	-0.00235	0.004117	-17.40	0.1237	0.1375
Side wall	0.00556	-0.000539	-0.0014197	0.03149	-34.79	0.0912	0.09975

6.19.1 Heat transfer coefficient results





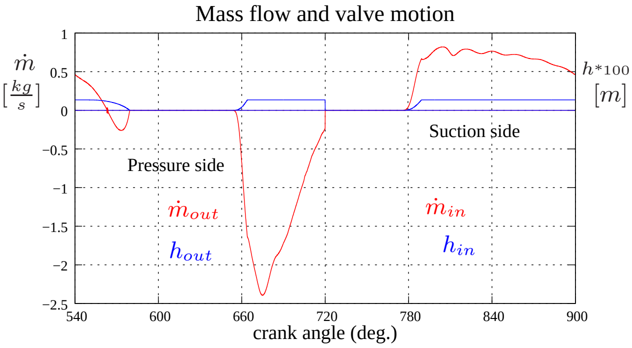


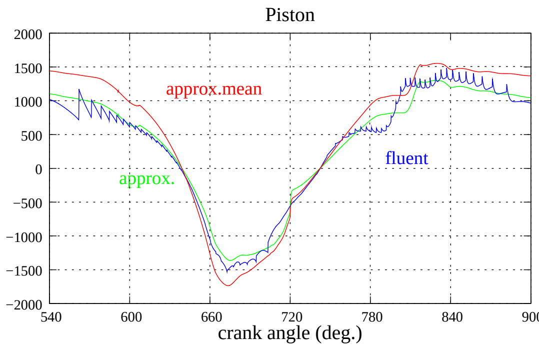


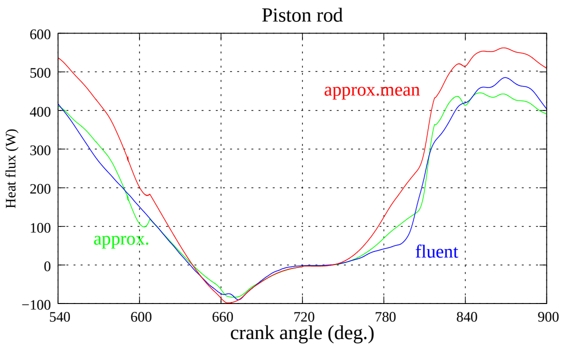
6.20 Case 20

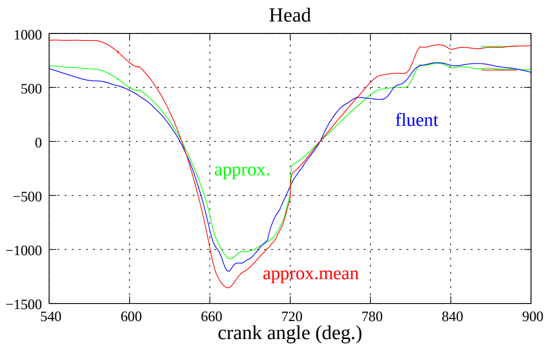
Values:

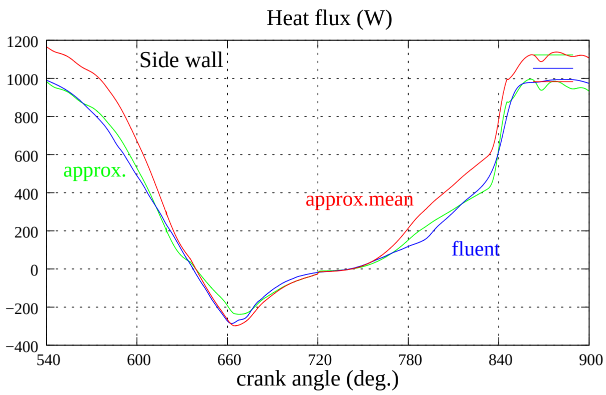
- Piston stroke: 140mm (standard value 90)
- Rod length: 250mm (standard value)
- Cra. speed: 2000 $\min^{-1}$ (standard value 980)
- Gas: air (standard value)
- $p_{in} = 3$bar, $p_{out} = 9$bar (standard $p_{in} = 1$, $p_{out} = 5$)









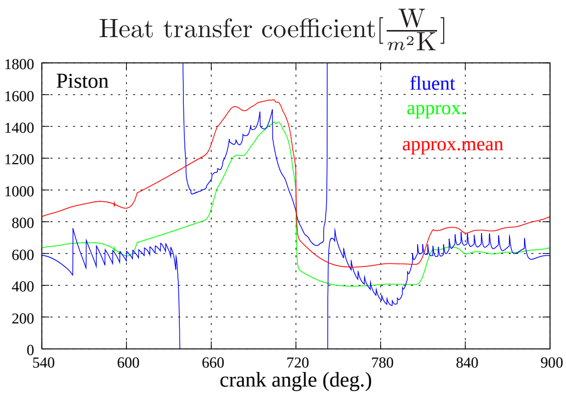


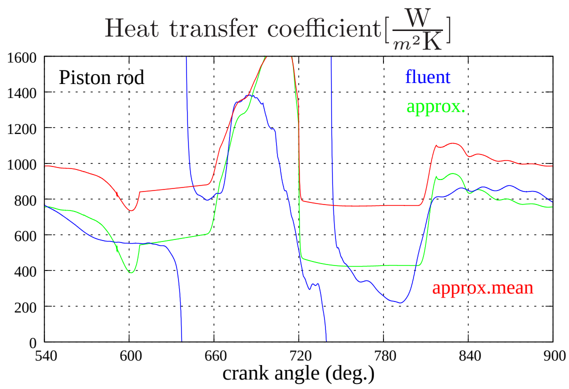
*The results valid for "half" of the compressor (axial symmetry)

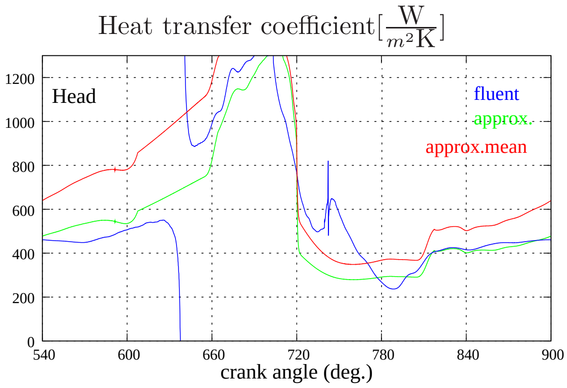
Tables of coefficients

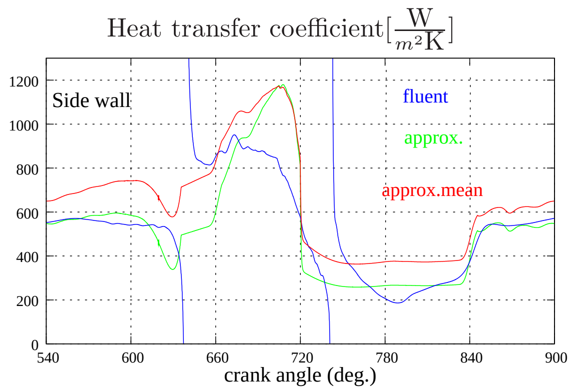
	St_{in}	St_{out}	St_k	Nu/Re	φ_0	error	error mean
Head	0.003	-0.00081	-0.0024187	0.02356	-28.14	0.1151	0.3147
Piston rod	0.01247	-0.001212	-0.000929	0.02724	-28.14	0.0979	0.3255
Piston	0.00561	-0.000817	-0.002127	0.0293	-28.14	0.1345	0.3171
Side wall	0.00832	-0.00077	-0.001421	0.01927	-56.28	0.0599	0.2229

6.20.1 Heat transfer coefficient results





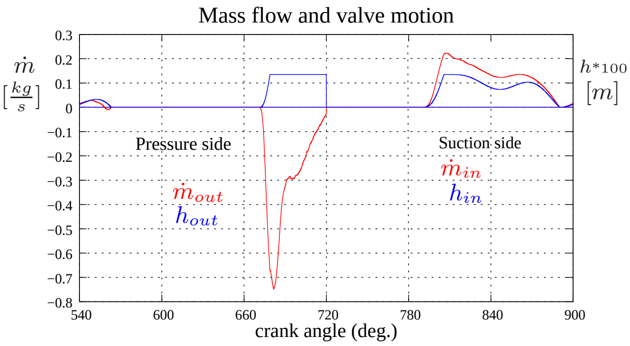


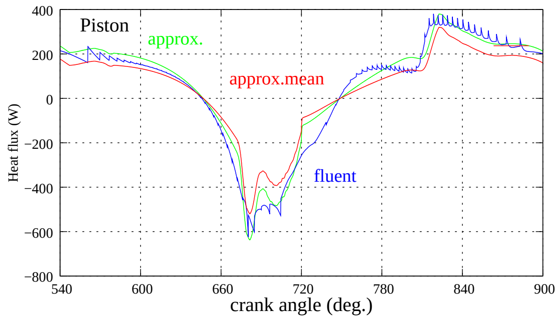


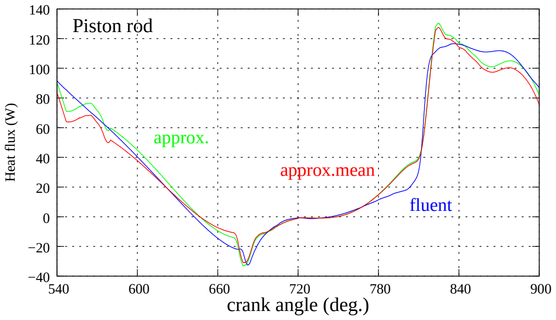
6.21 Case 21

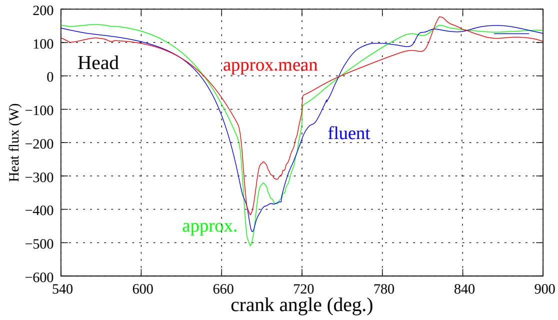
Values:

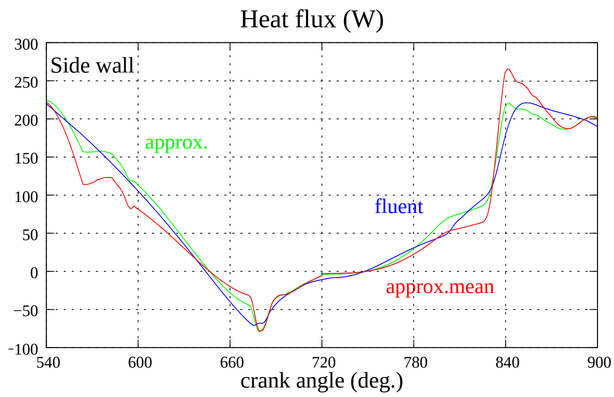
- Piston stroke: 90mm (standard value 90)
- Rod length: 250mm (standard value)
- Rod diameter: 50mm (standard value 45)
- Cra. speed: 980 min^{-1} (standard value 980)
- Gas: air (standard value)
- p_{in} = 1bar, p_{out} = 5bar (standard $p_{in} = 1$, $p_{out} = 5$)









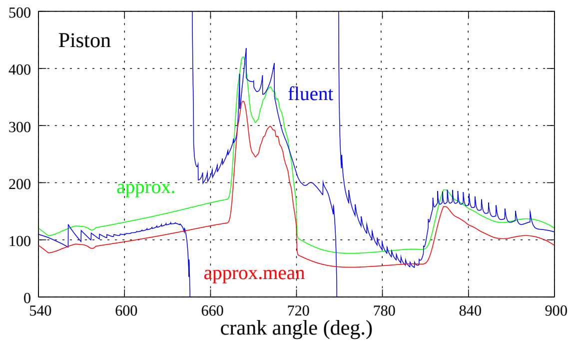


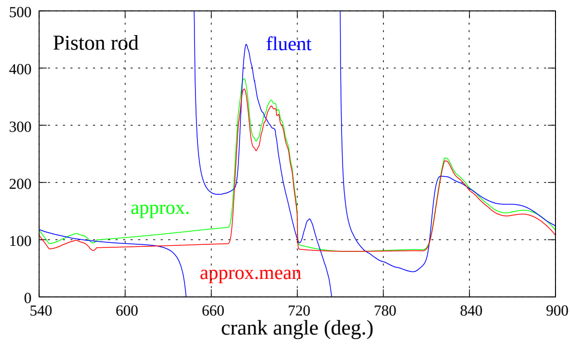
*The results valid for "half" of the compressor (axial symmetry)

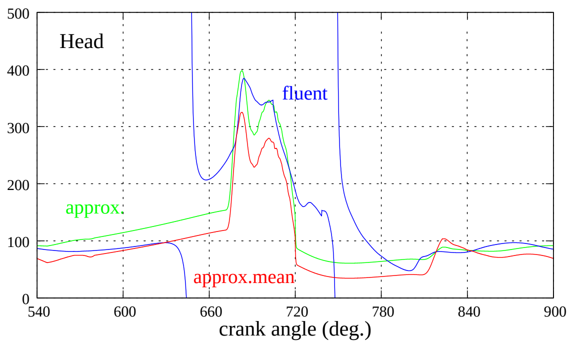
Tables of coefficients

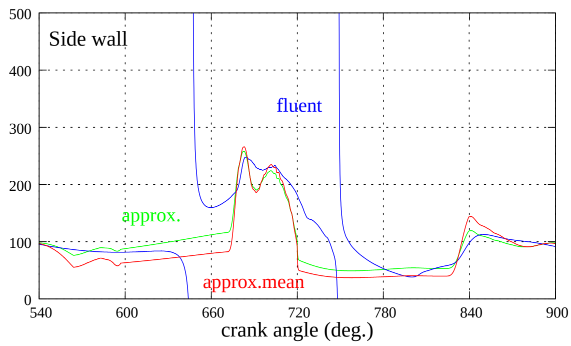
	St_{in}	St_{out}	St_k	Nu/Re	φ_0	error	error mean
Head	0.00121	-0.00081	0.0043	0.0483	-16.96	0.1927	0.289
Piston rod	0.0086	-0.00084	-0.00195	0.0503	-16.96	0.1000	0.1203
Piston	0.0057	-0.00082	-0.0044	0.05707	-16.96	0.1708	0.2728
Side wall	0.00421	-0.00047	-0.00313	0.0377	-33.92	0.0917	0.1831

6.21.1 Heat transfer coefficient results





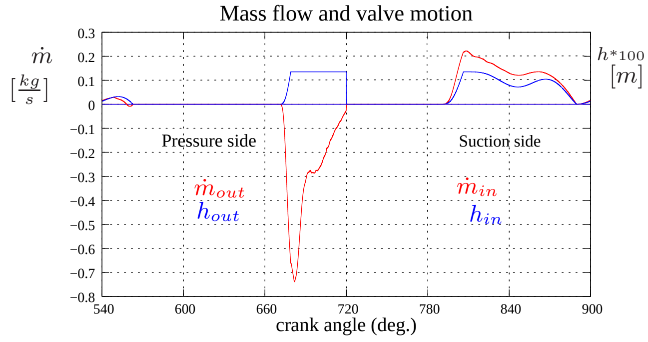


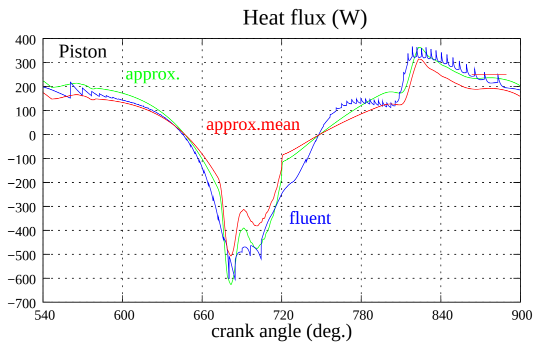


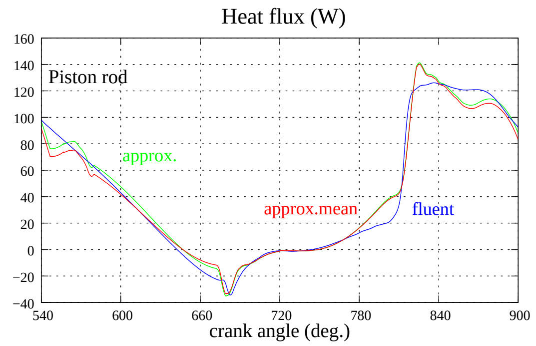
6.22 Case 22

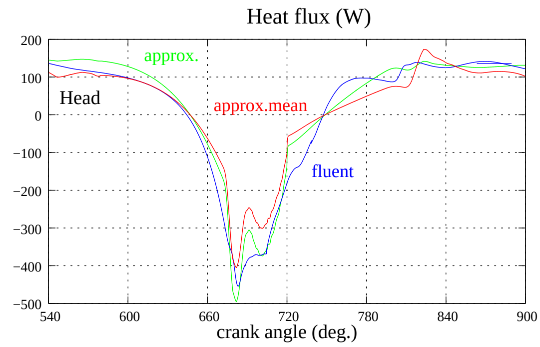
Values:

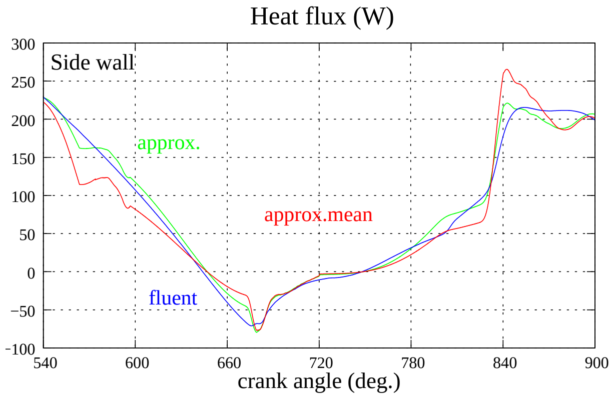
- Piston stroke: 90mm (standard value 90)
- Rod length: 250mm (standard value)
- Rod diameter: 55mm (standard value 45)
- Cra. speed: 980 $\min^{-1}$ (standard value 980)
- Gas: air (standard value)
- $p_{in} = 1$bar, $p_{out} = 5$bar (standard $p_{in} = 1$, $p_{out} = 5$)









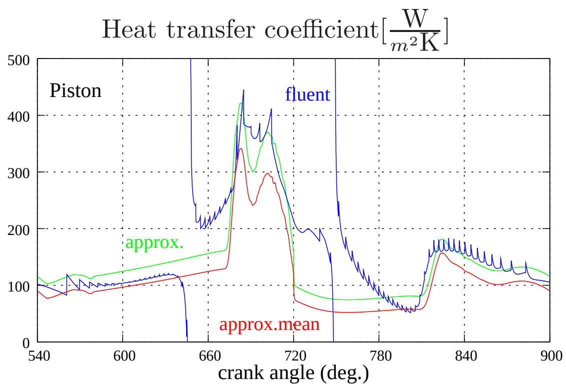


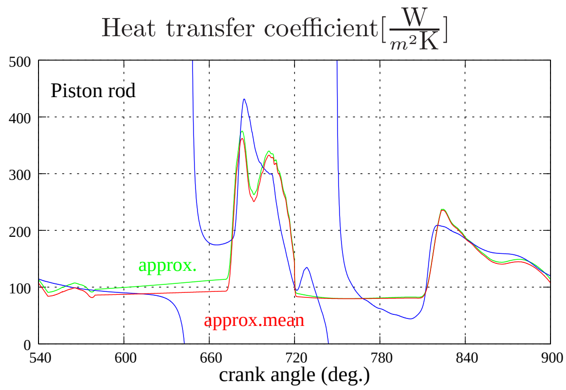
*The results valid for “half” of the compressor (axial symmetry)

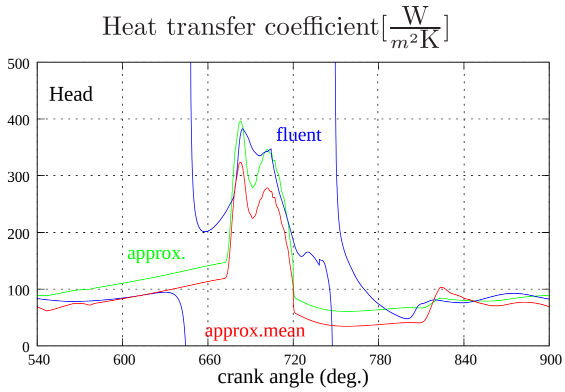
Tables of coefficients

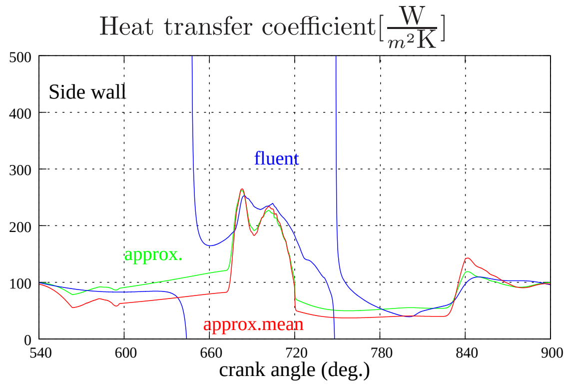
	St_{in}	St_{out}	St_k	Nu/Re	φ_0	error	error mean
Head	0.00098	-0.000824	-0.00401	0.0471	-17.05	0.1961	0.2870
Piston rod	0.00843	-0.00084	-0.00159	0.04921	-17.05	0.1020	0.1132
Piston	0.0055	-0.00086	-0.00407	0.05481	-17.05	0.1787	0.2667
Side wall	0.0041	-0.00047	-0.003321	0.03874	-34.10	0.0913	0.1926

6.22.1 Heat transfer coefficient results





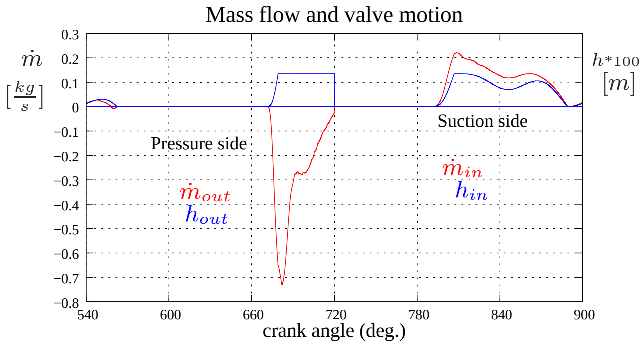


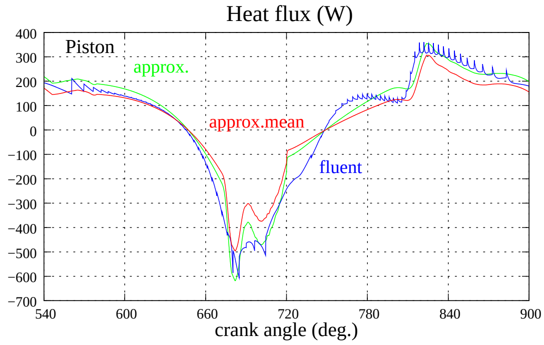


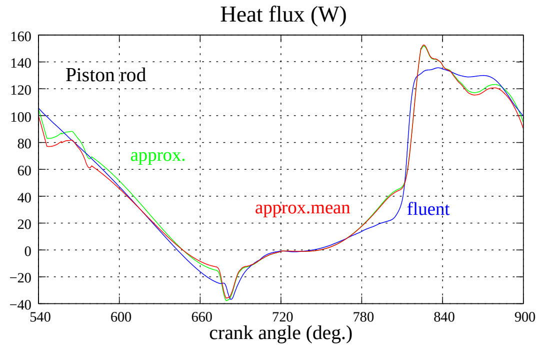
6.23 Case 23

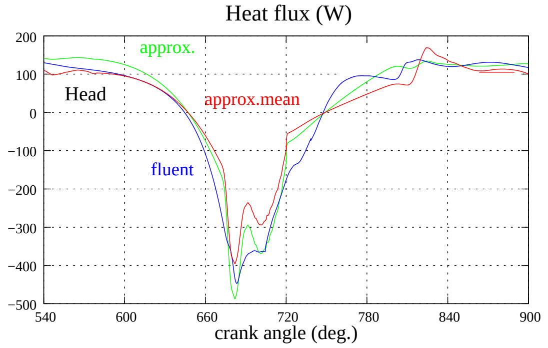
Values:

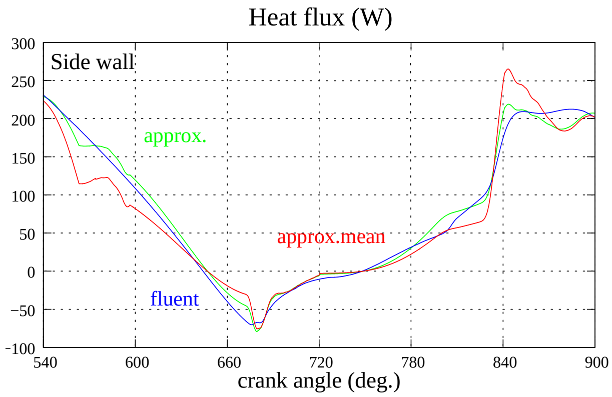
- Piston stroke: 90mm (standard value 90)
- Rod length: 250mm (standard value)
- Rod diameter: 60mm (standard value 45)
- Cra. speed: 980 $\min^{-1}$ (standard value 980)
- Gas: air (standard value)
- $p_{in} = 1$bar, $p_{out} = 5$bar (standard $p_{in} = 1$, $p_{out} = 5$)









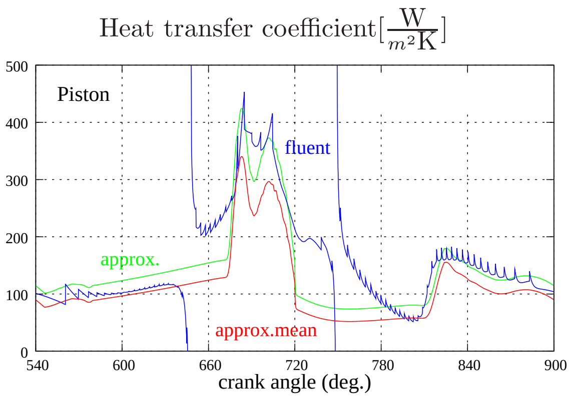


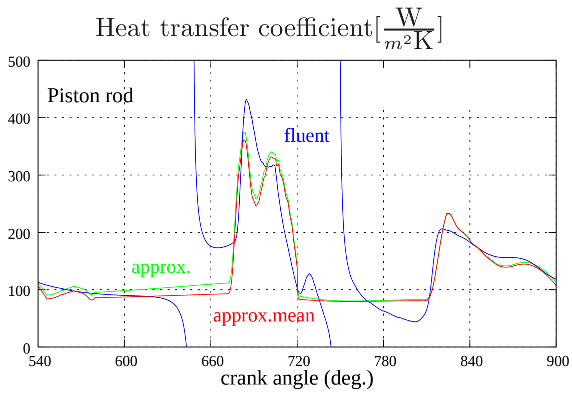
*The results valid for "half" of the compressor (axial symmetry)

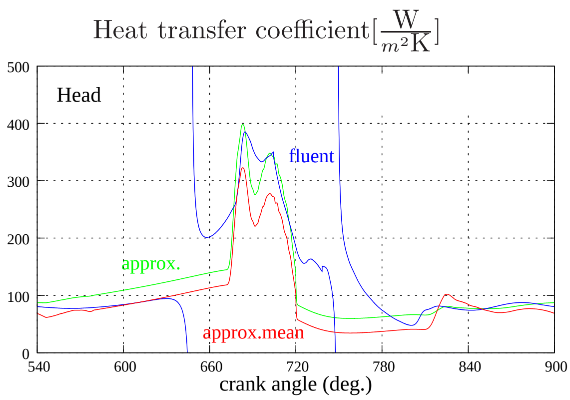
Tables of coefficients

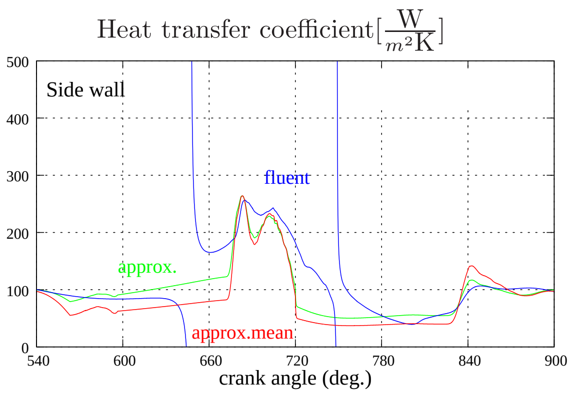
	St_{in}	St_{out}	St_k	Nu/Re	φ_0	error	error mean
Head	0.00087	-0.00084	-0.00398	0.04656	-17.13	0.1977	0.2888
Piston rod	0.00825	-0.00085	-0.001467	0.0491	-17.13	0.1035	0.1126
Piston	0.00554	-0.00088	-0.004	0.0543	-17.13	0.1807	0.2687
Side wall	0.004	-0.000478	0.00339	0.0392	-34.25	0.0897	0.1991

6.23.1 Heat transfer coefficient results





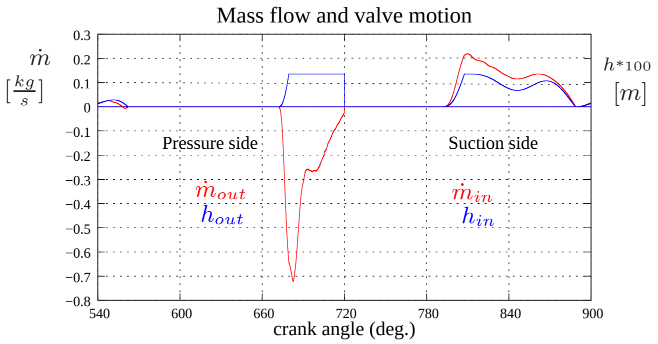


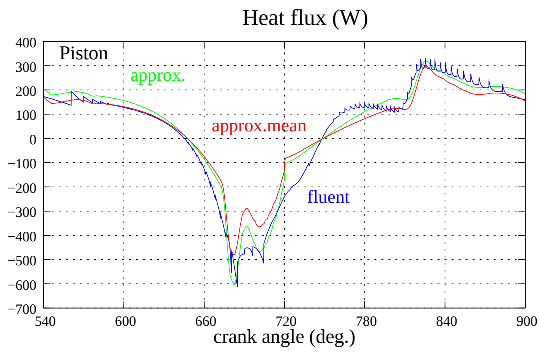


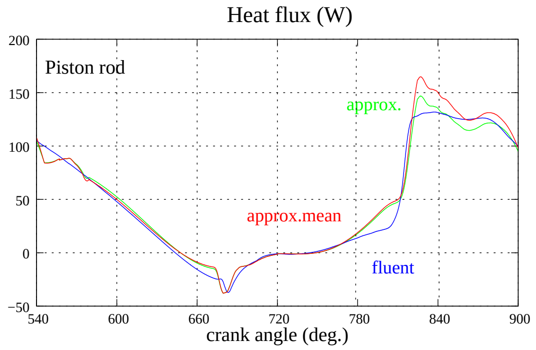
6.24 Case 24

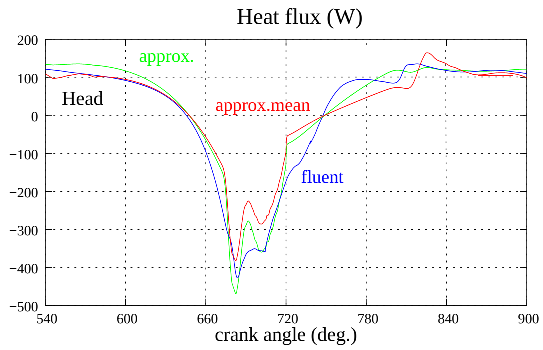
Values:

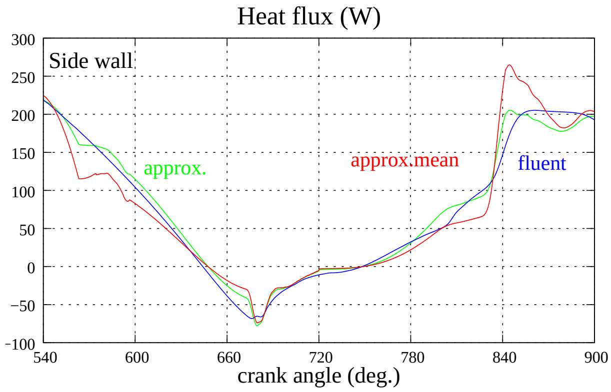
- Piston stroke: 90mm (standard value 90)
- Rod length: 250mm (standard value)
- Rod diameter: 65mm (standard value 45)
- Cra. speed: 980 min^{-1} (standard value 980)
- Gas: air (standard value)
- $p_{in} = 1$bar, $p_{out} = 5$bar (standard $p_{in} = 1$, $p_{out} = 5$)









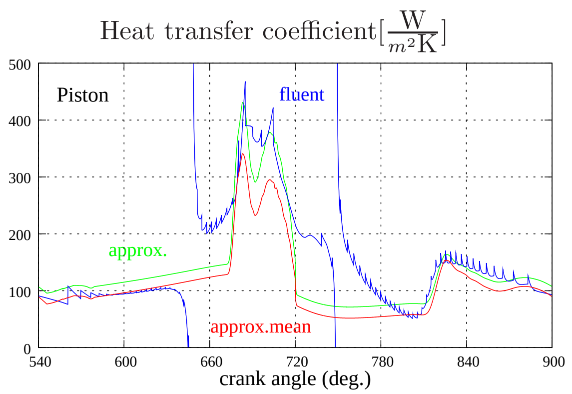


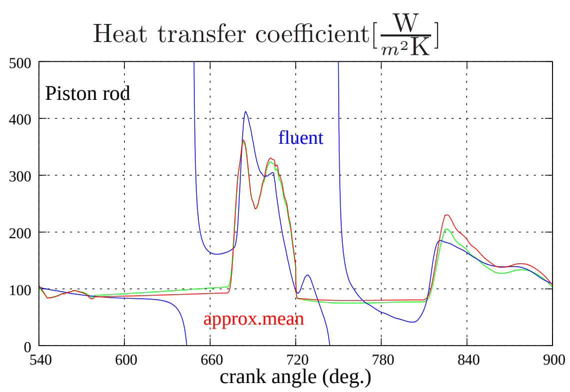
*The results valid for “half” of the compressor (axial symmetry)

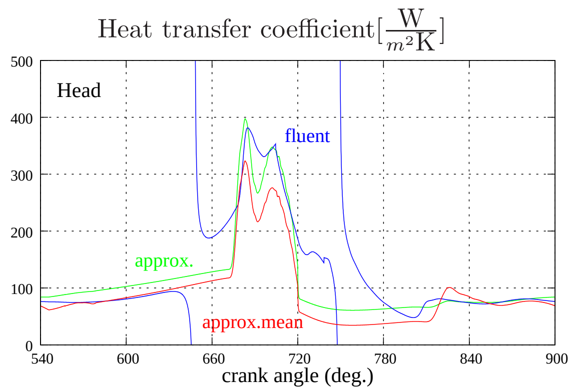
Tables of coefficients

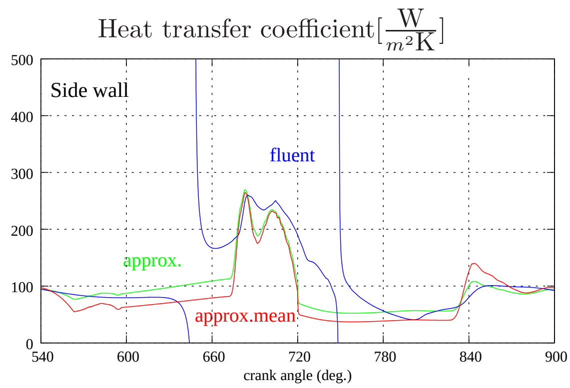
	St_{in}	St_{out}	St_k	Nu/Re	φ_0	error	error mean
Head	0.000663	-0.000865	-0.00339	0.04509	-17.28	0.2026	0.2864
Piston rod	0.007204	-0.00082	-0.001335	0.04575	-17.28	0.1011	0.1307
Piston	0.00492	-0.00093	-0.00354	0.05123	-17.28	0.1935	0.2639
Side wall	0.00343	-0.00052	-0.00286	0.03852	-34.56	0.1028	0.2111

6.24.1 Heat transfer coefficient results

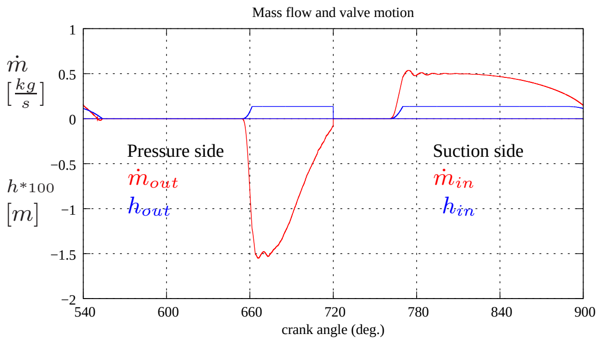


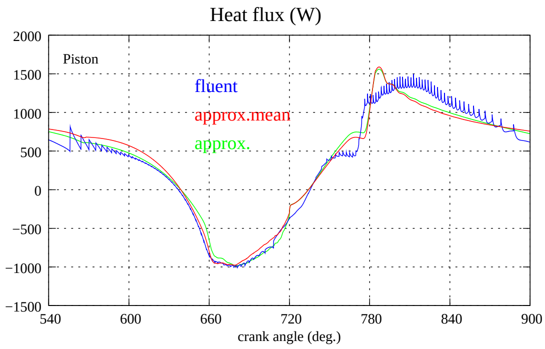


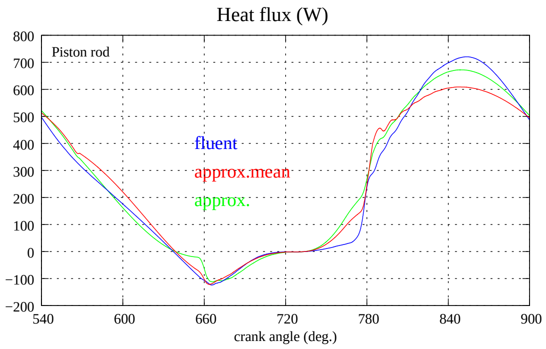


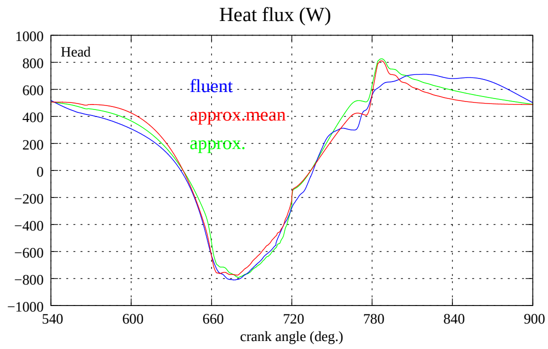


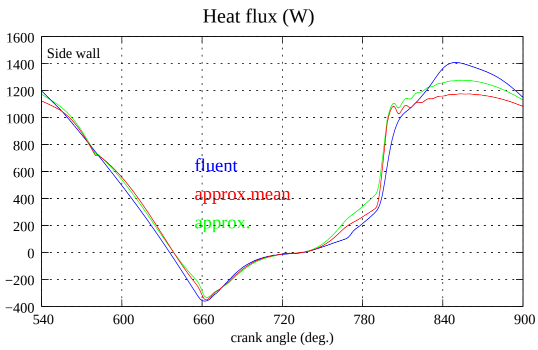
6.25 Methan Case 1

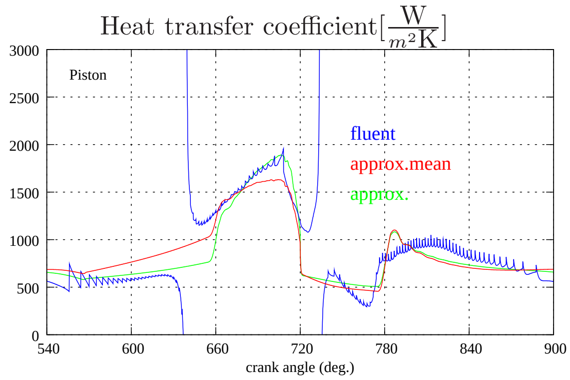


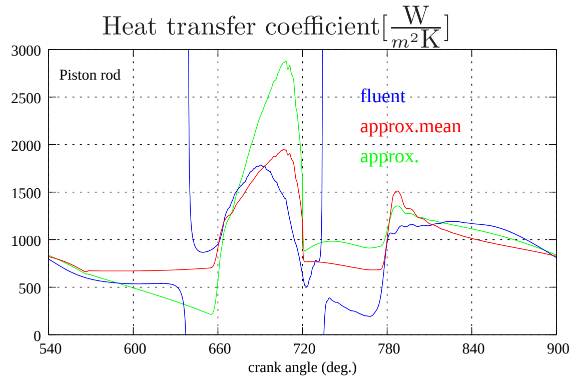


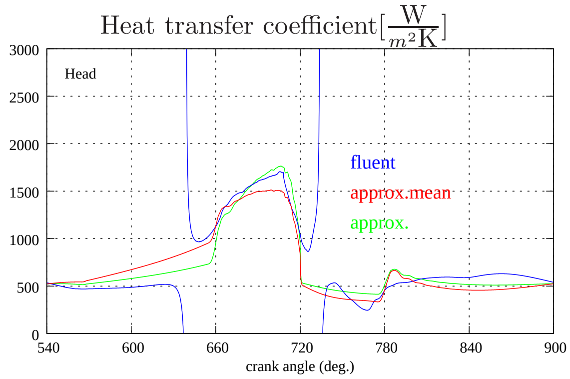


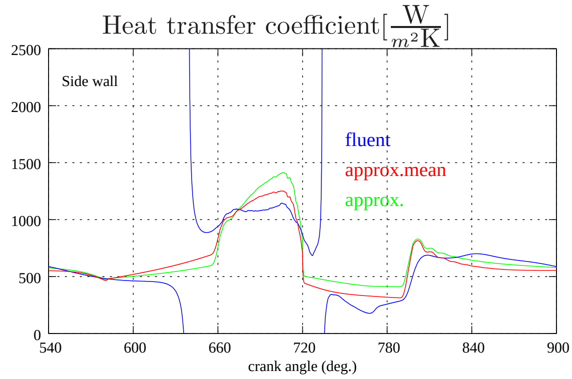




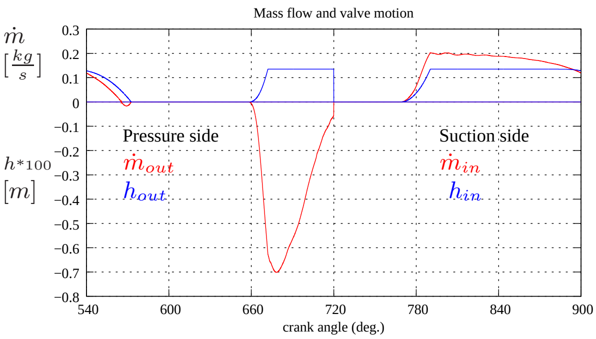

Heat transfer coefficient$[\frac{W}{m^2K}]$
Piston
fluent
approx.mean
approx.
crank angle (deg.)

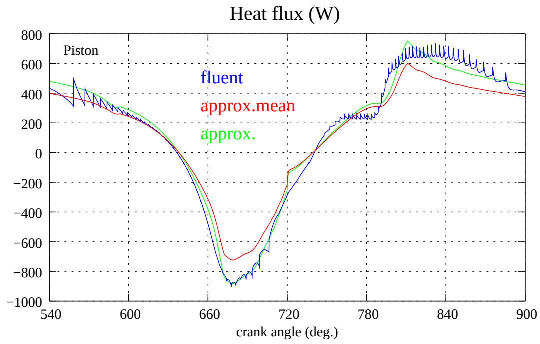

Heat transfer coefficient$[\frac{W}{m^2K}]$
Piston rod
fluent
approx.mean
approx.
crank angle (deg.)

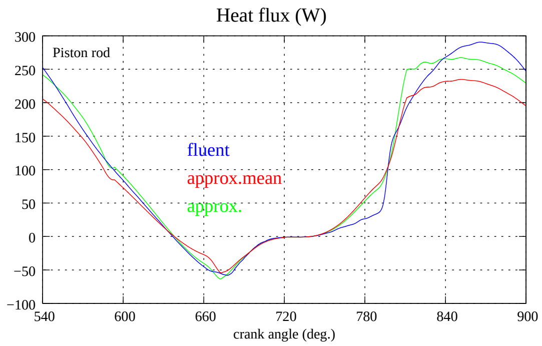

Heat transfer coefficient$[\frac{W}{m^2K}]$
Head
fluent
approx.mean
approx.
crank angle (deg.)

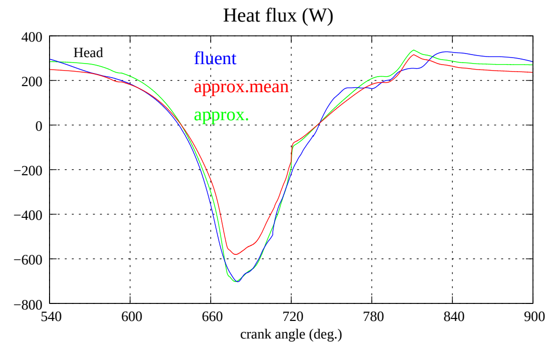

Heat transfer coefficient$[\frac{W}{m^2K}]$
Side wall
fluent
approx.mean
approx.
crank angle (deg.)

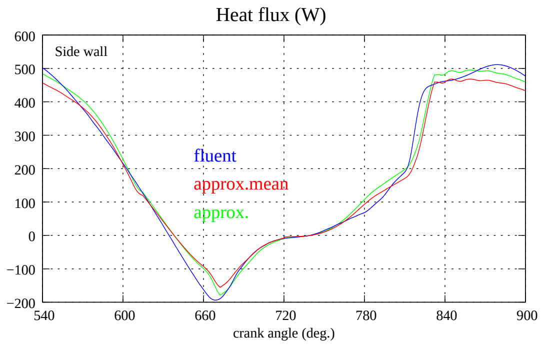
6.26 Methan Case 2

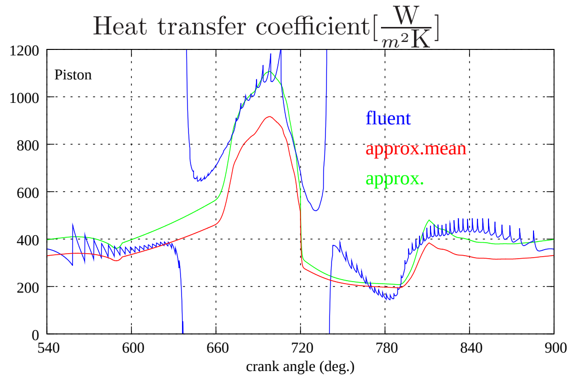


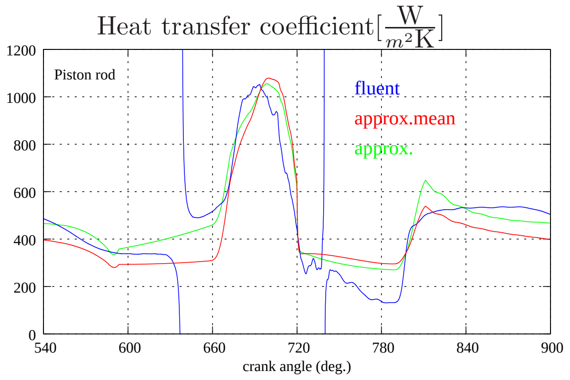


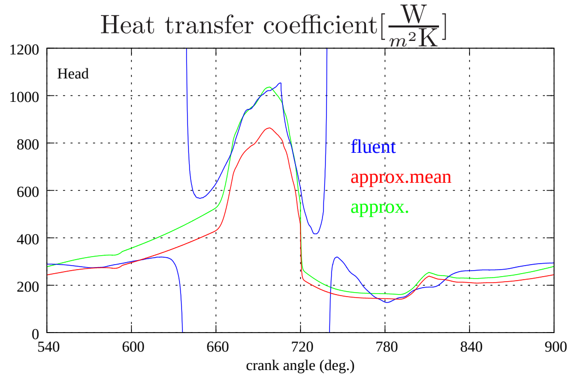


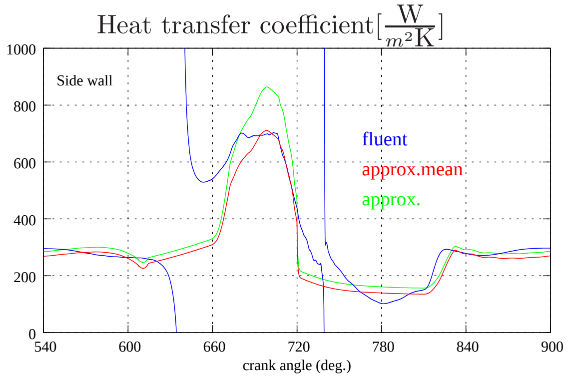




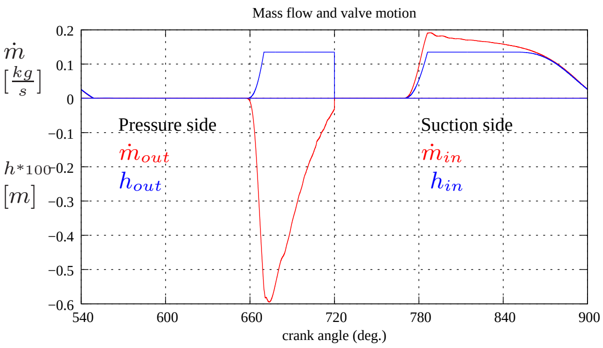

Heat transfer coefficient[$\frac{W}{m^2K}$]
Piston
fluent
approx.mean
approx.
crank angle (deg.)

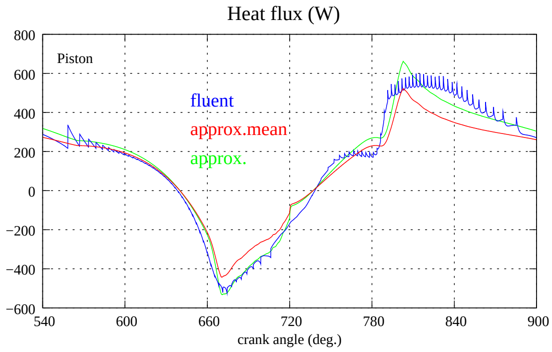

Heat transfer coefficient[$\frac{W}{m^2K}$]
Piston rod
fluent
approx.mean
approx.
crank angle (deg.)

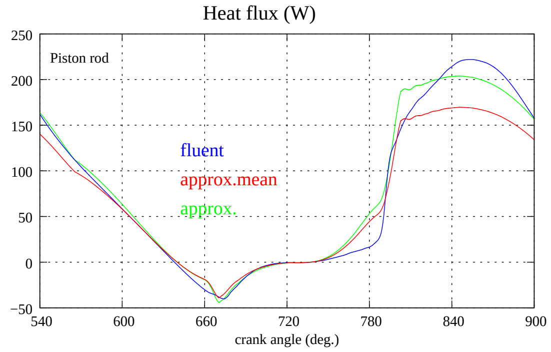

Heat transfer coefficient[$\frac{W}{m^2K}$]
Head
fluent
approx.mean
approx.
crank angle (deg.)

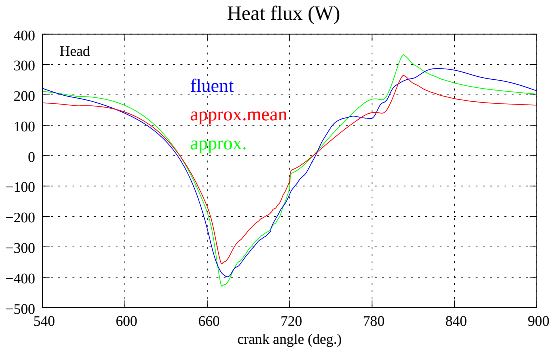

Heat transfer coefficient[$\frac{W}{m^2K}$]
Side wall
fluent
approx.mean
approx.
crank angle (deg.)

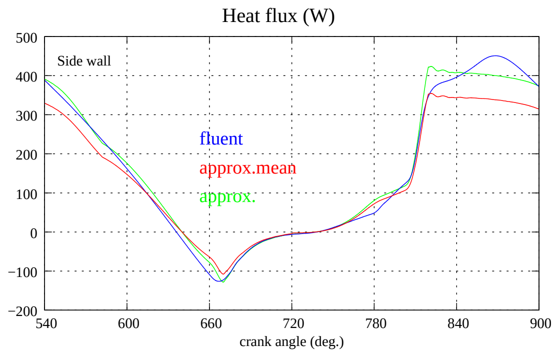
6.27 Methan Case 3

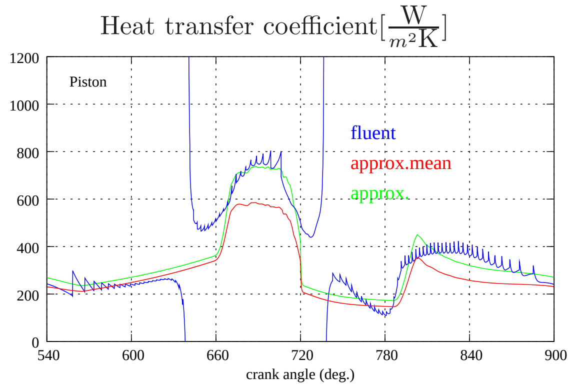


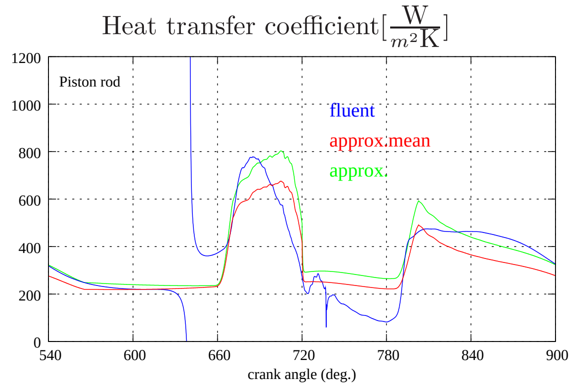


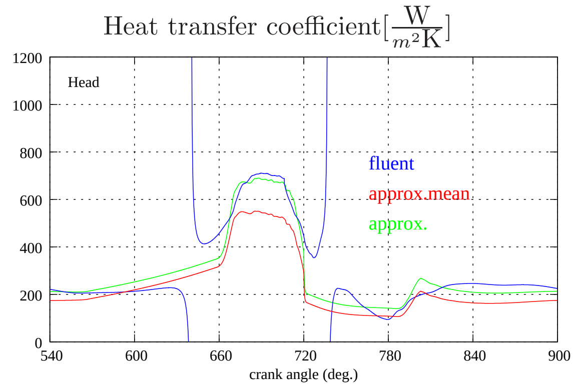


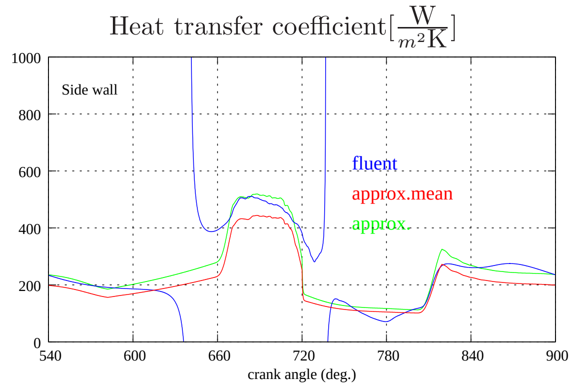




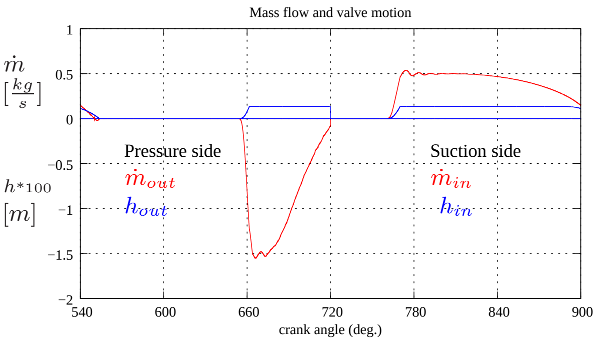

Heat transfer coefficient[W/m²K]
Piston
fluent
approx.mean
approx.
crank angle (deg.)

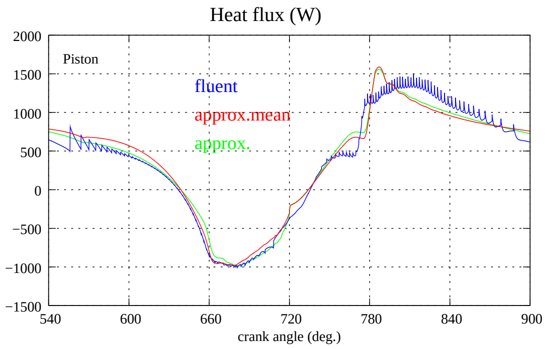

Heat transfer coefficient[W/m²K]
Piston rod
fluent
approx.mean
approx.
crank angle (deg.)

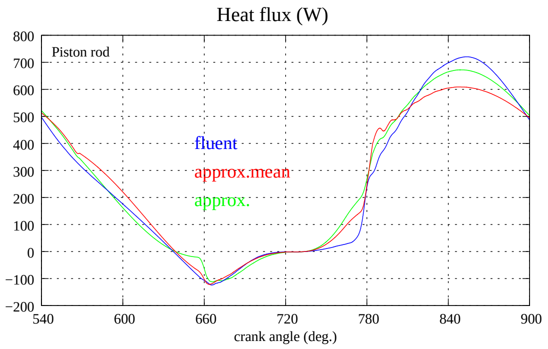

Heat transfer coefficient[W/m²K]
Head
fluent
approx.mean
approx.
crank angle (deg.)

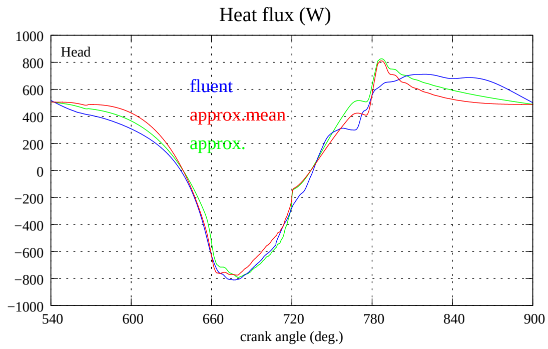

Heat transfer coefficient[W/m²K]
Side wall
fluent
approx.mean
approx.
crank angle (deg.)

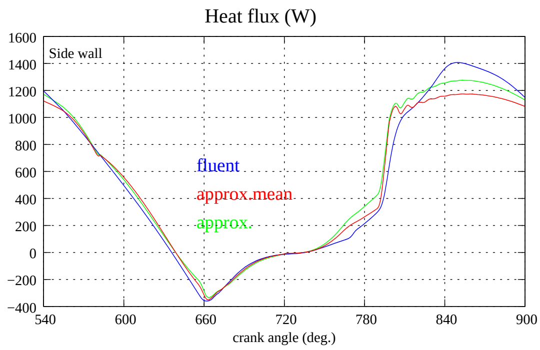
6.28 Methan Case 4

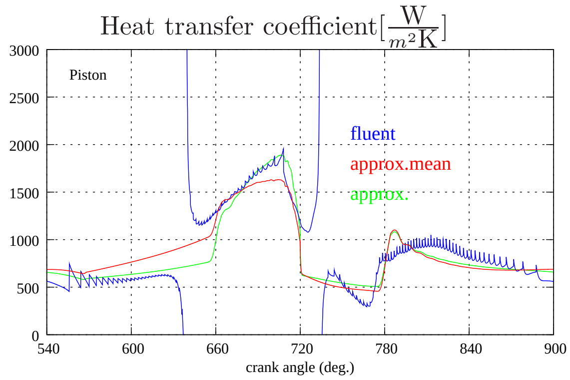


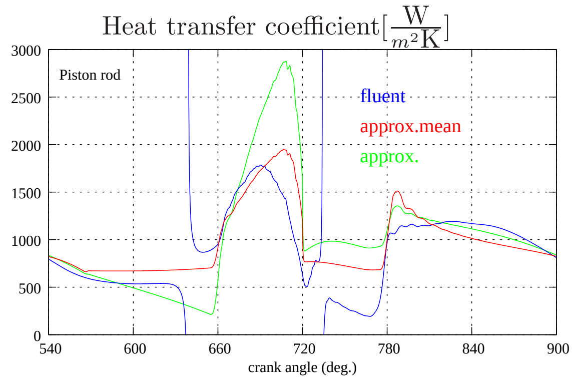


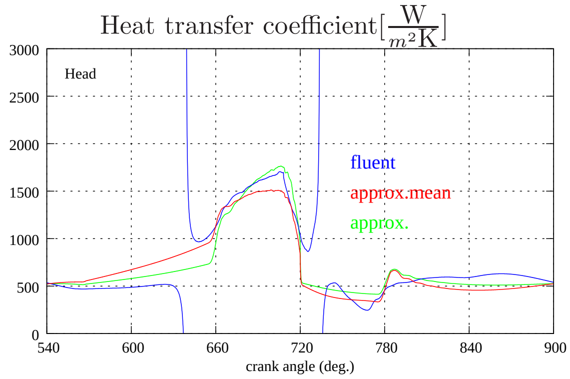


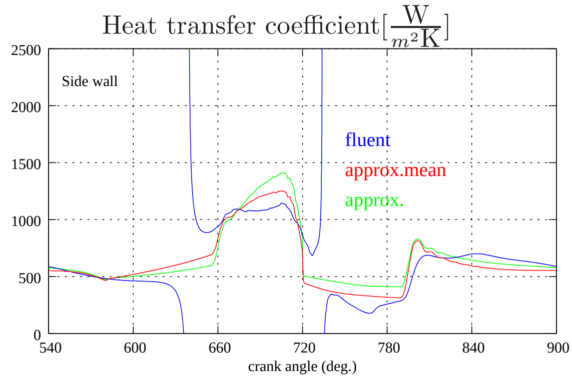




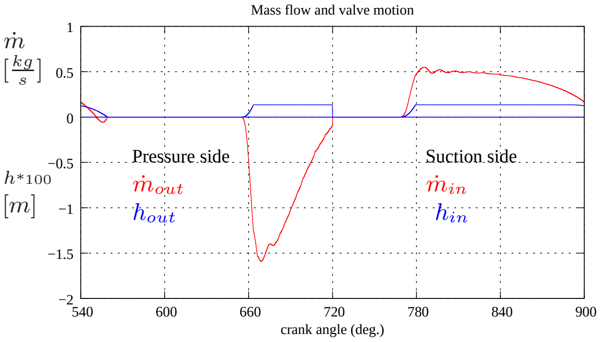

Heat transfer coefficient[$\frac{W}{m^2K}$]
Piston
fluent
approx.mean
approx.
crank angle (deg.)

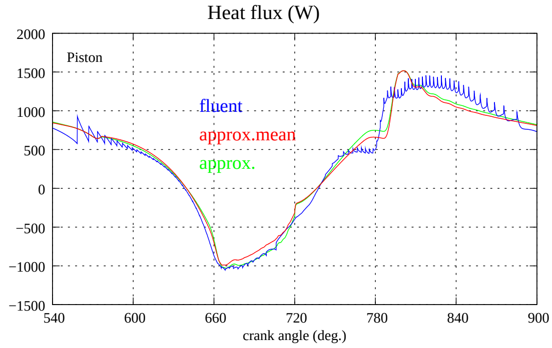

Heat transfer coefficient[$\frac{W}{m^2K}$]
Piston rod
fluent
approx.mean
approx.
crank angle (deg.)

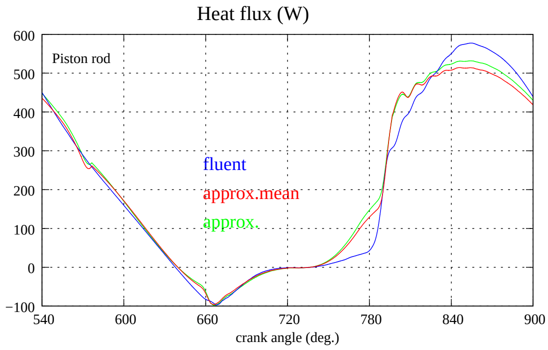

Heat transfer coefficient[$\frac{W}{m^2K}$]
Head
fluent
approx.mean
approx.
crank angle (deg.)

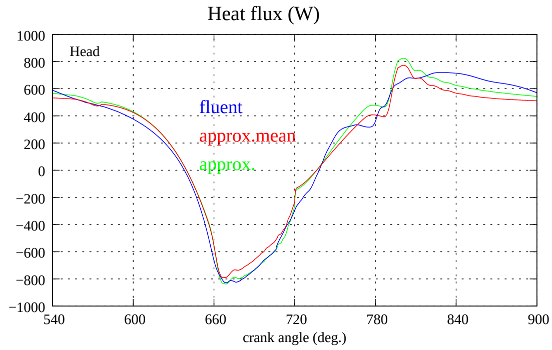

Heat transfer coefficient[$\frac{W}{m^2K}$]
Side wall
fluent
approx.mean
approx.
crank angle (deg.)

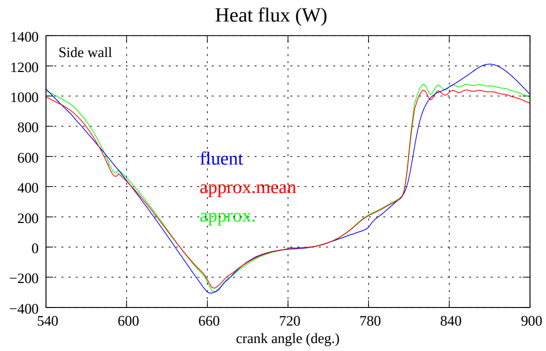
6.29 Methan Case 5

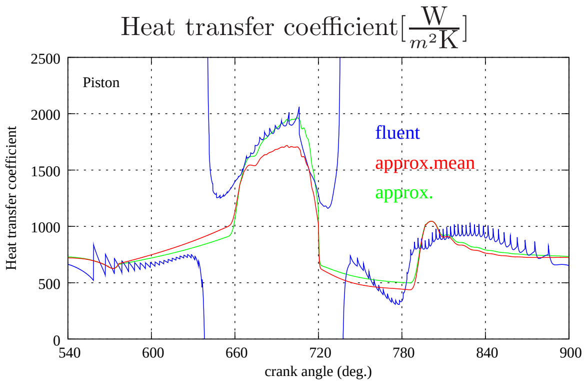


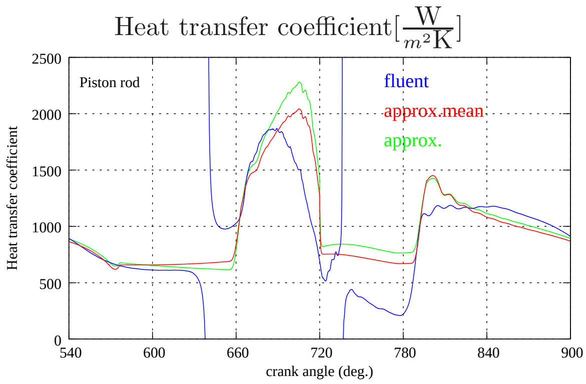


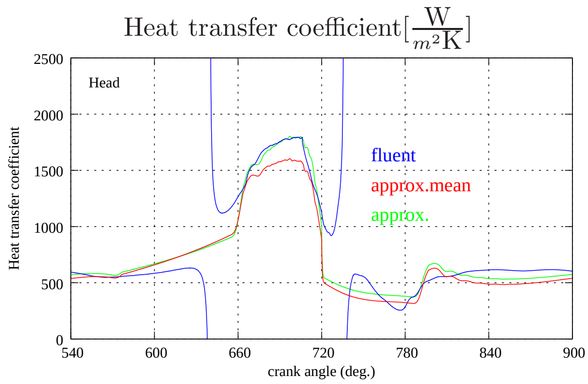


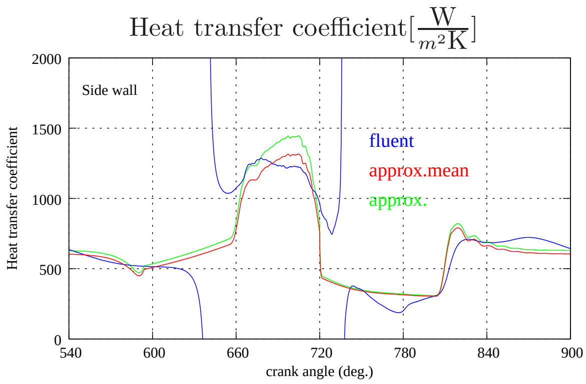




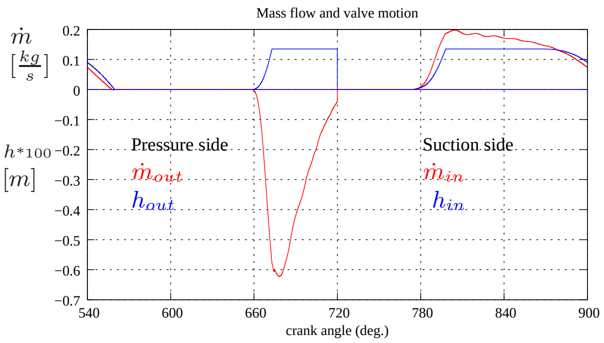

Heat transfer coefficient$[\frac{W}{m^2K}]$
Piston
fluent
approx.mean
approx.
Heat transfer coefficient
crank angle (deg.)
0
500
1000
1500
2000
2500
540
600
660
720
780
840
900

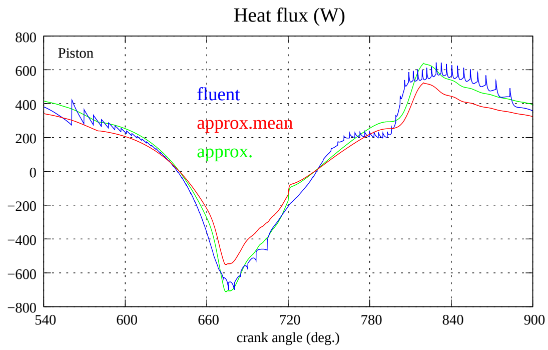

Heat transfer coefficient$[\frac{W}{m^2K}]$
Piston rod
fluent
approx.mean
approx.
Heat transfer coefficient
crank angle (deg.)
0
500
1000
1500
2000
2500
540
600
660
720
780
840
900

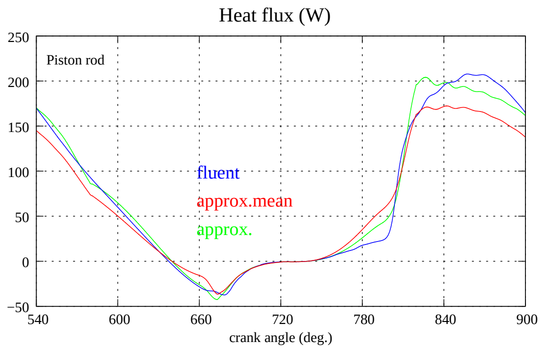

Heat transfer coefficient$[\frac{W}{m^2K}]$
Head
fluent
approx.mean
approx.
Heat transfer coefficient
crank angle (deg.)
0
500
1000
1500
2000
2500
540
600
660
720
780
840
900

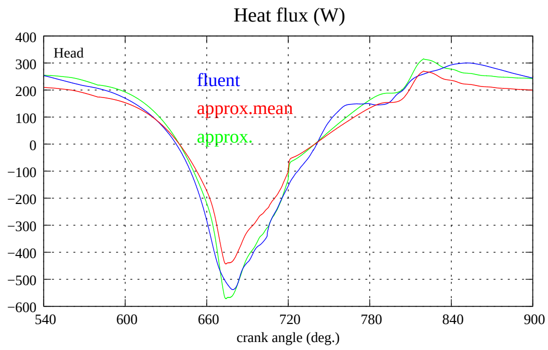

Heat transfer coefficient$[\frac{W}{m^2K}]$
Side wall
fluent
approx.mean
approx.
Heat transfer coefficient
crank angle (deg.)
0
500
1000
1500
2000
540
600
660
720
780
840
900

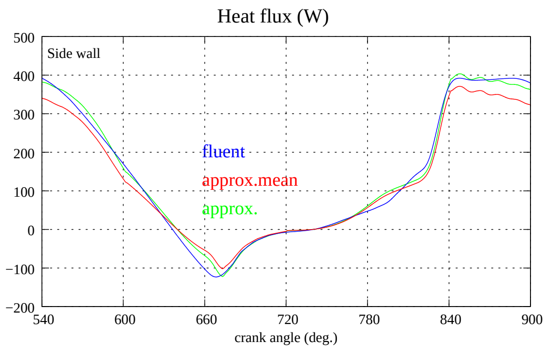
6.30 Methan Case 6

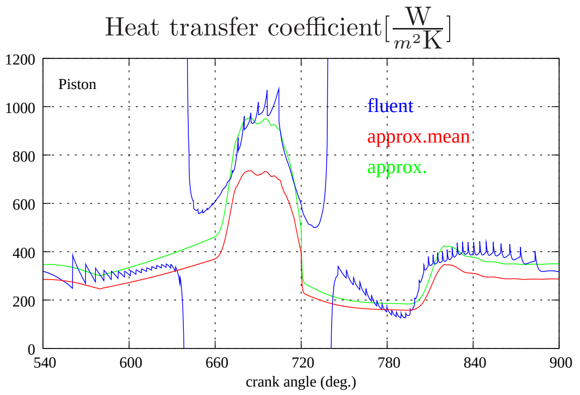


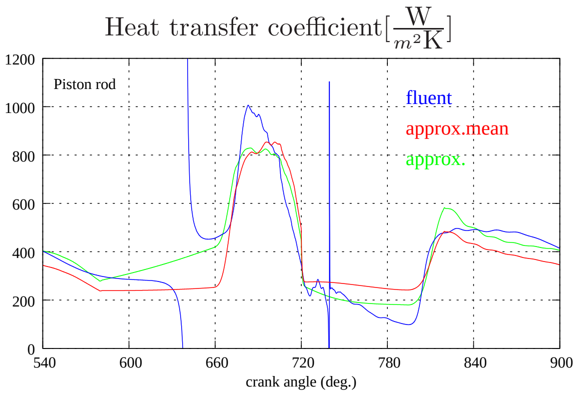


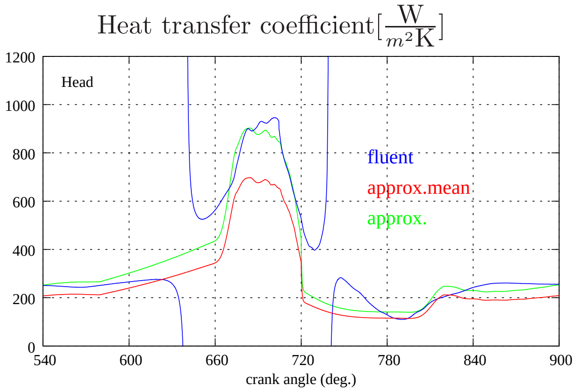


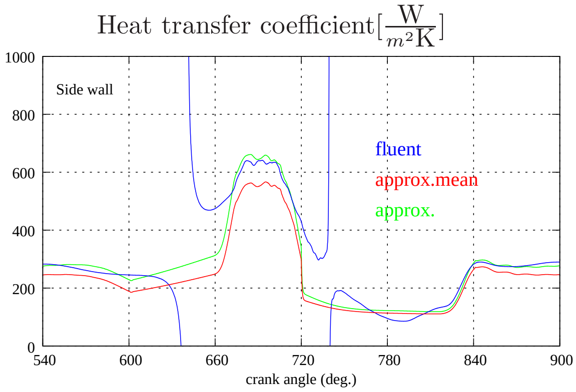




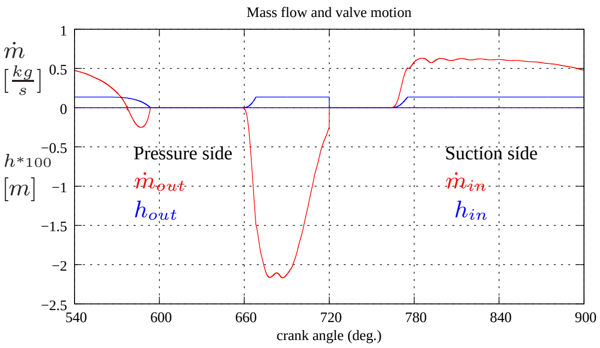

Heat transfer coefficient[$\frac{W}{m^2K}$]
Piston
fluent
approx.mean
approx.
crank angle (deg.)

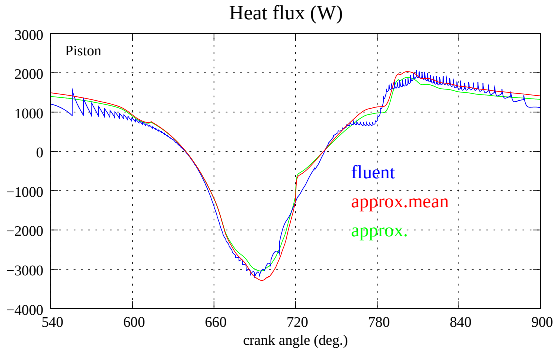

Heat transfer coefficient[$\frac{W}{m^2K}$]
Piston rod
fluent
approx.mean
approx.
crank angle (deg.)

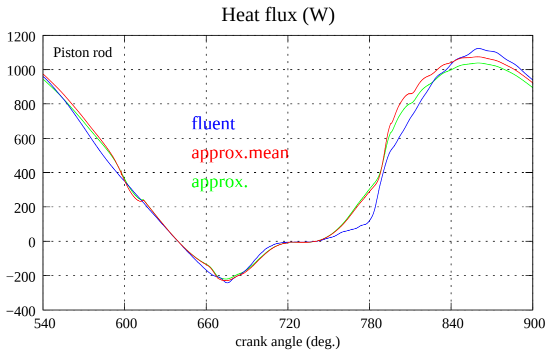

Heat transfer coefficient[$\frac{W}{m^2K}$]
Head
fluent
approx.mean
approx.
crank angle (deg.)

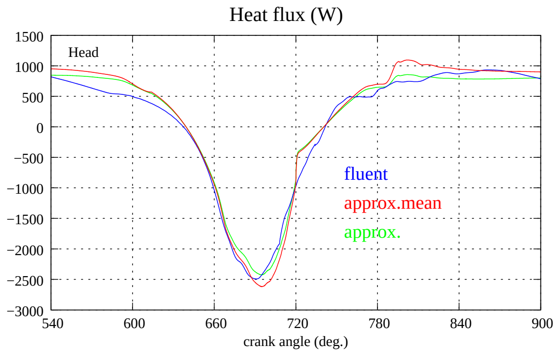

Heat transfer coefficient[$\frac{W}{m^2K}$]
Side wall
fluent
approx.mean
approx.
crank angle (deg.)

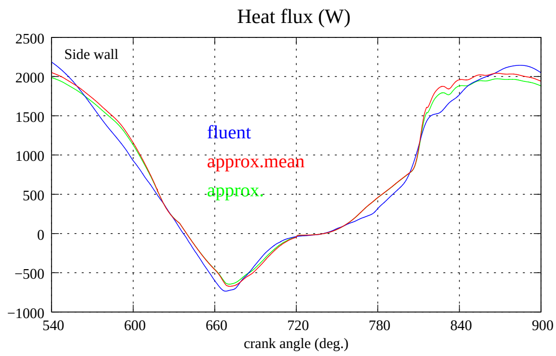
6.31 Methan Case 7

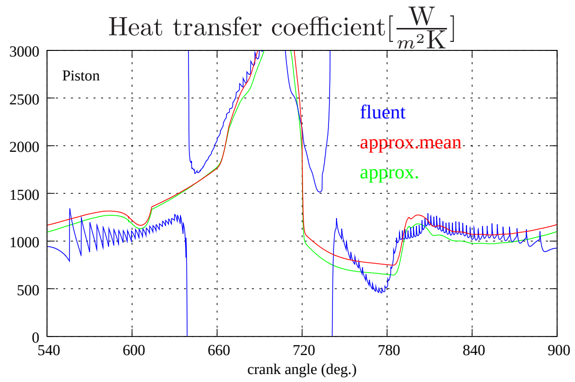


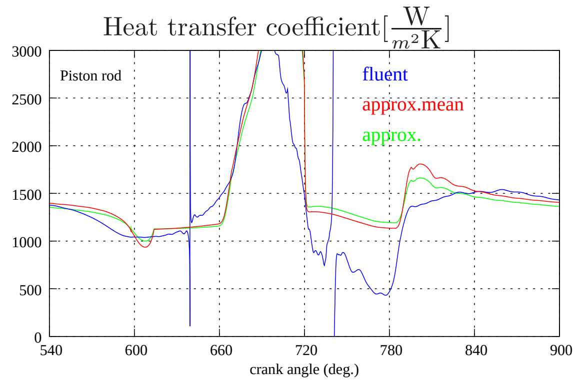


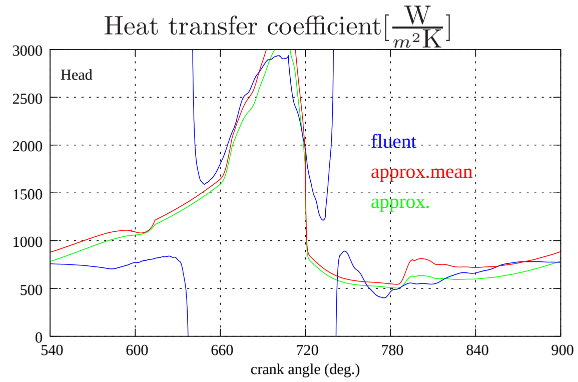


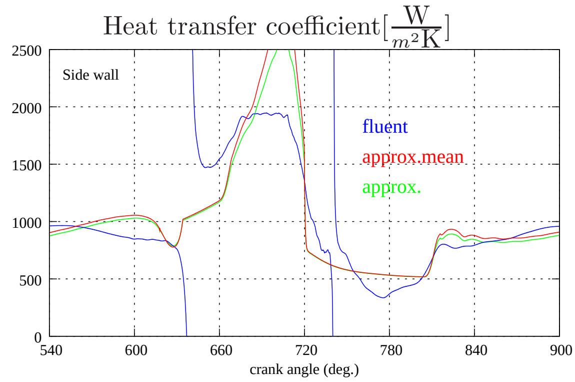




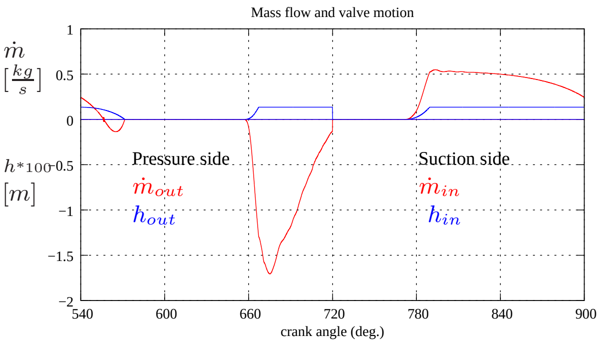

Heat transfer coefficient$[\frac{W}{m^2K}]$
Piston
fluent
approx.mean
approx.
3000
2500
2000
1500
1000
500
0
540
600
660
720
780
840
900
crank angle (deg.)

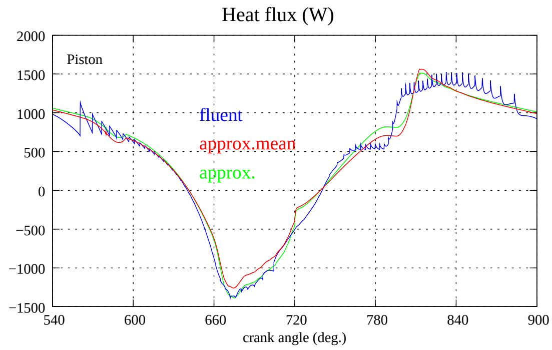

Heat transfer coefficient$[\frac{W}{m^2K}]$
Piston rod
fluent
approx.mean
approx.
3000
2500
2000
1500
1000
500
0
540
600
660
720
780
840
900
crank angle (deg.)

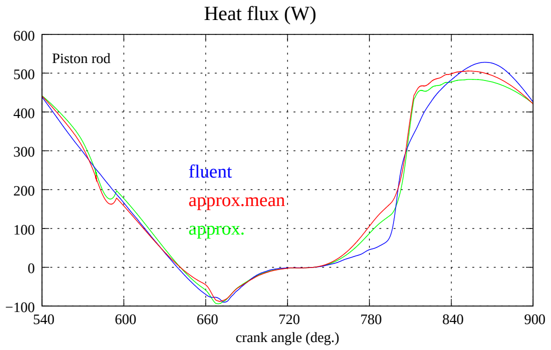

Heat transfer coefficient$[\frac{W}{m^2K}]$
Head
fluent
approx.mean
approx.
3000
2500
2000
1500
1000
500
0
540
600
660
720
780
840
900
crank angle (deg.)

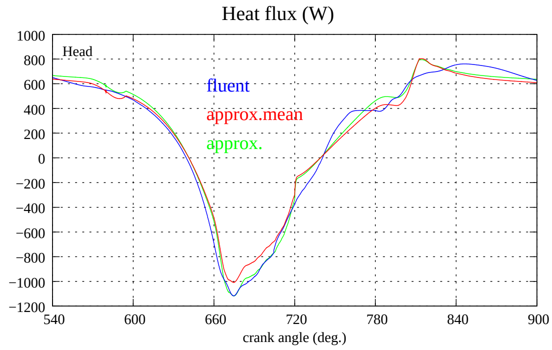

Heat transfer coefficient$[\frac{W}{m^2K}]$
Side wall
fluent
approx.mean
approx.
2500
2000
1500
1000
500
0
540
600
660
720
780
840
900
crank angle (deg.)

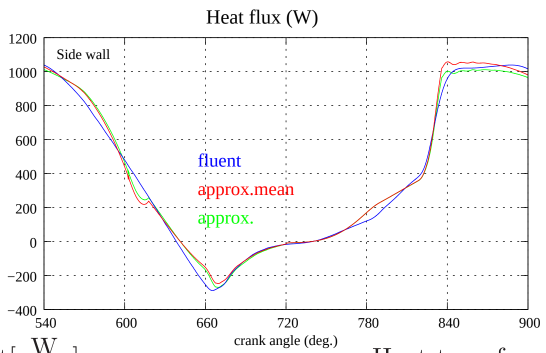
6.32 Methan Case 8

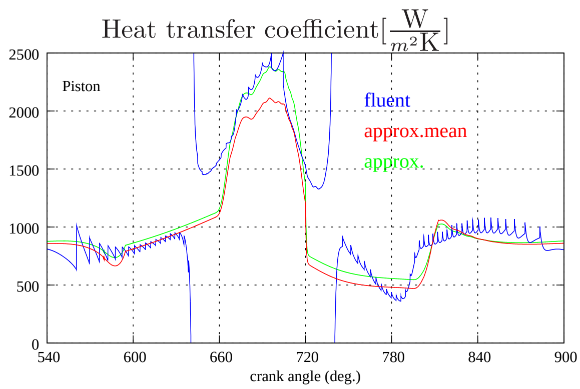


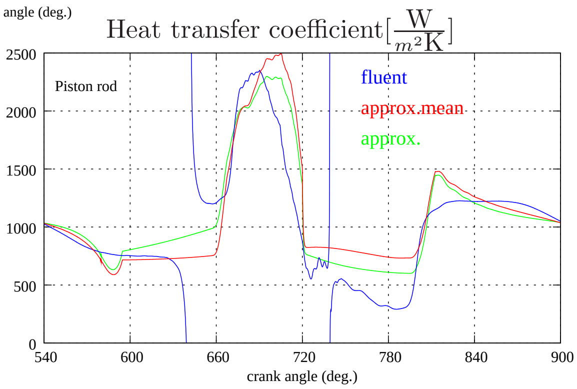


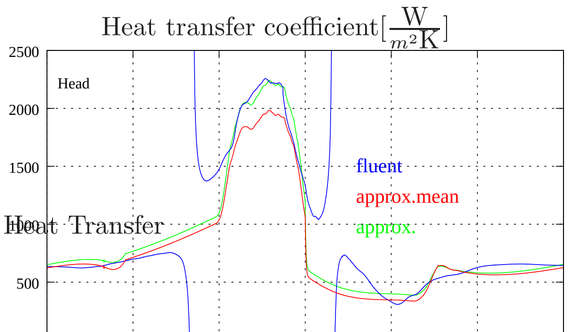


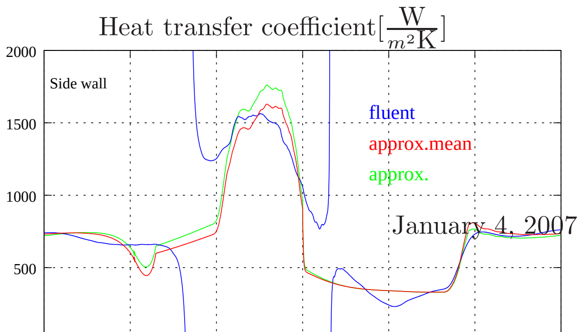




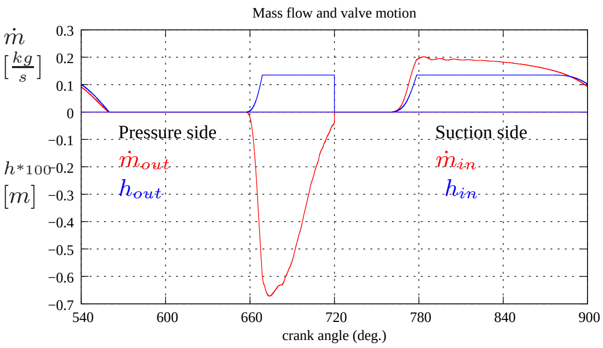


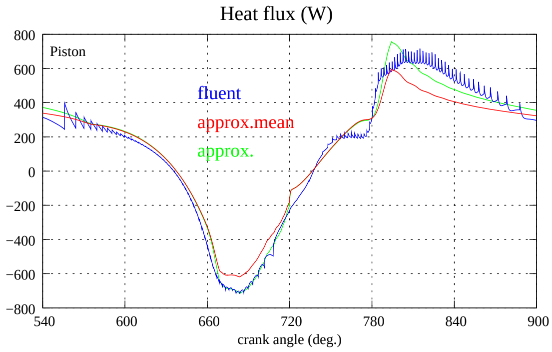


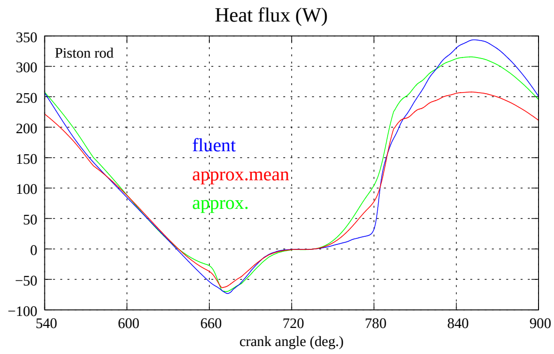


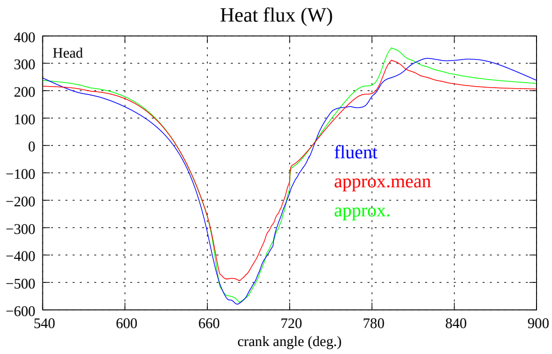


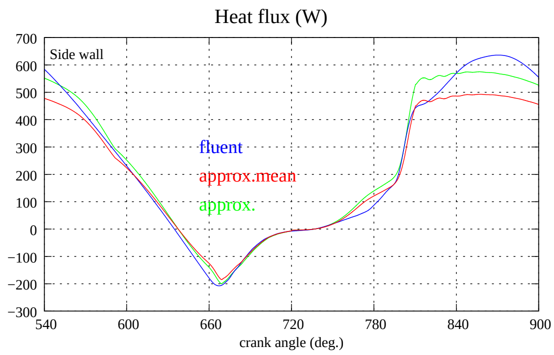
6.33 Methan Case 9

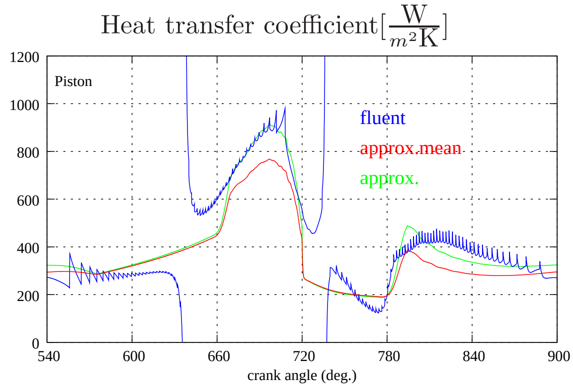


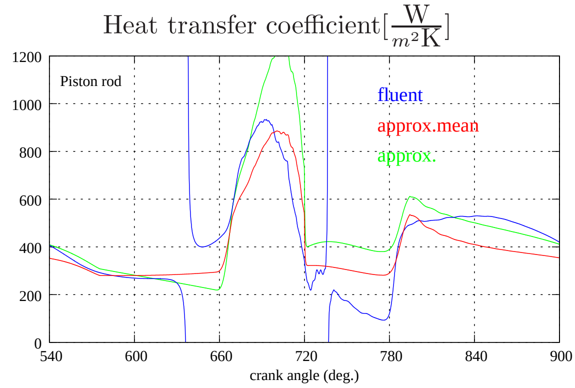


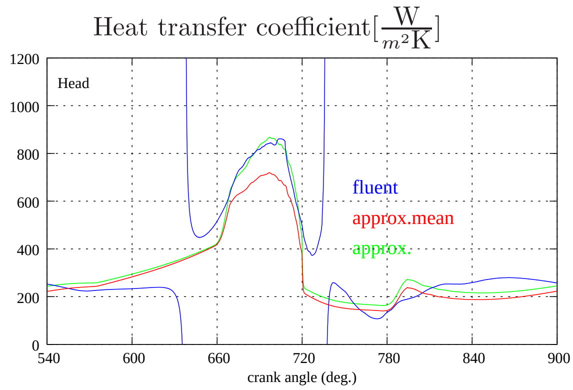


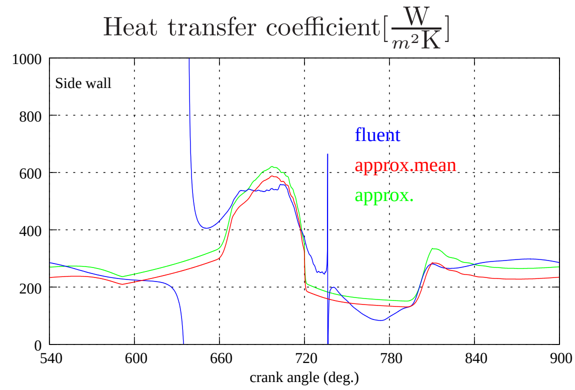




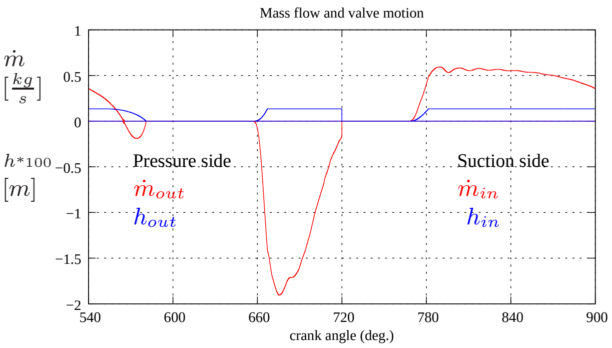

Heat transfer coefficient[$\frac{W}{m^2K}$]
Piston
fluent
approx.mean
approx.
crank angle (deg.)
0
200
400
600
800
1000
1200
540
600
660
720
780
840
900

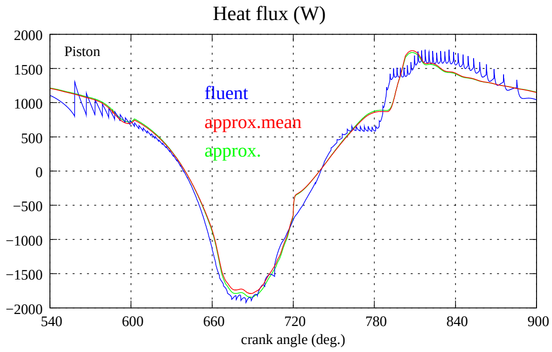

Heat transfer coefficient[$\frac{W}{m^2K}$]
Piston rod
fluent
approx.mean
approx.
crank angle (deg.)
0
200
400
600
800
1000
1200
540
600
660
720
780
840
900

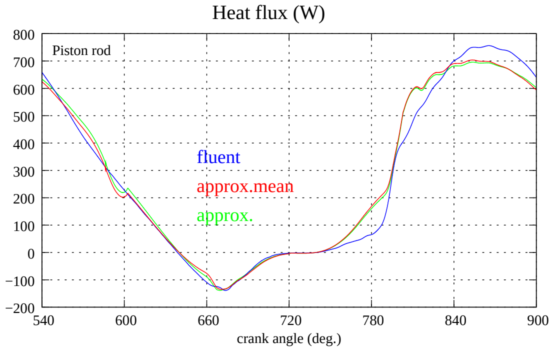

Heat transfer coefficient[$\frac{W}{m^2K}$]
Head
fluent
approx.mean
approx.
crank angle (deg.)
0
200
400
600
800
1000
1200
540
600
660
720
780
840
900

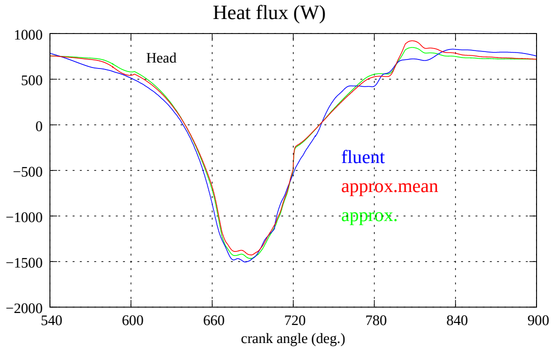

Heat transfer coefficient[$\frac{W}{m^2K}$]
Side wall
fluent
approx.mean
approx.
crank angle (deg.)
0
200
400
600
800
1000
540
600
660
720
780
840
900

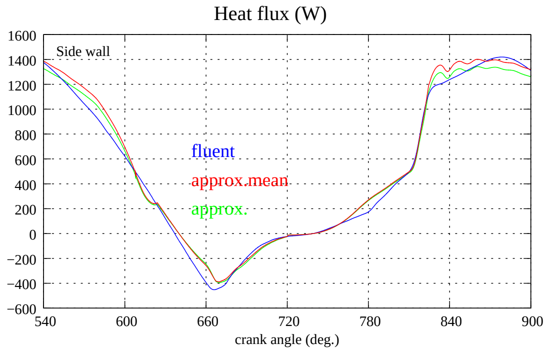
6.34 Methan Case 10

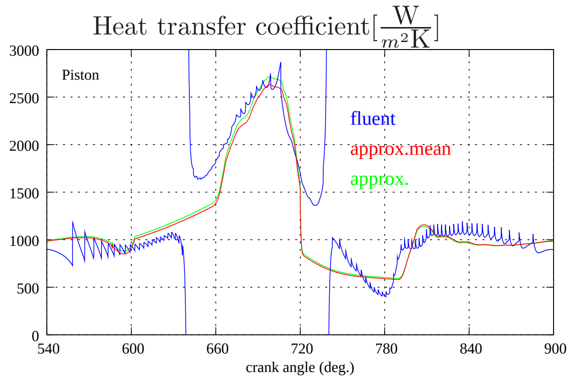


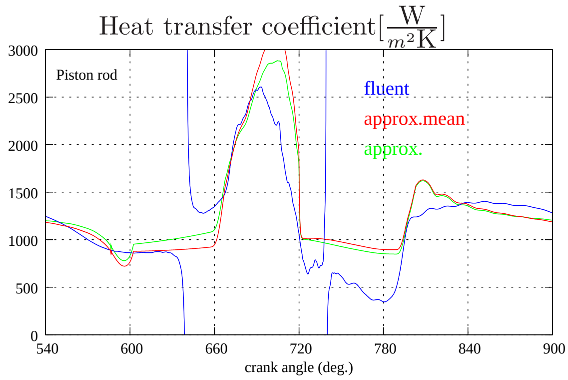


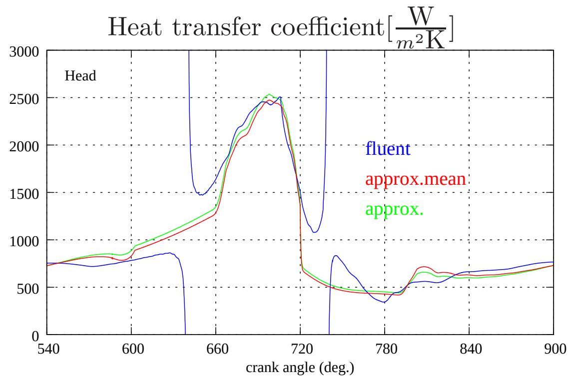


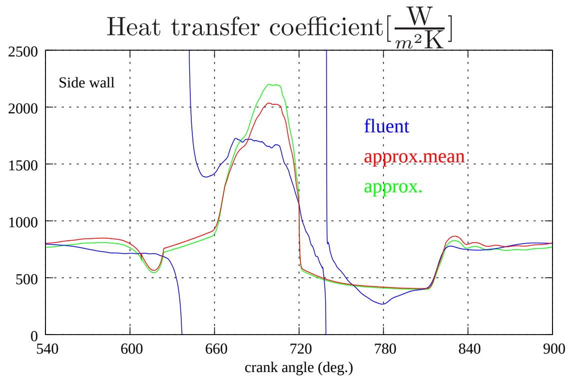




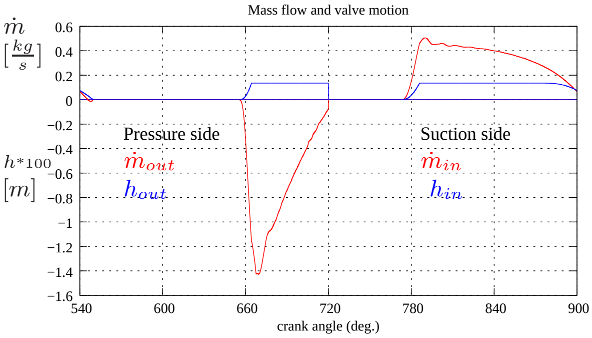

Heat transfer coefficient$[\frac{W}{m^2K}]$
Piston
fluent
approx.mean
approx.
crank angle (deg.)
0
500
1000
1500
2000
2500
3000
540
600
660
720
780
840
900

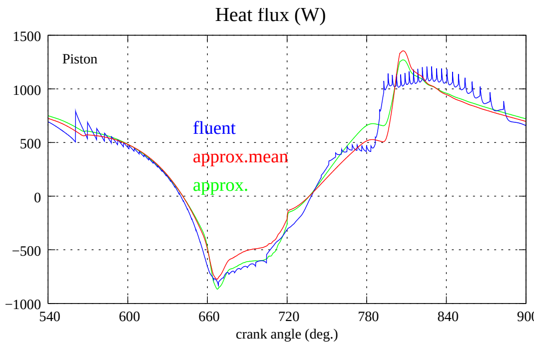

Heat transfer coefficient$[\frac{W}{m^2K}]$
Piston rod
fluent
approx.mean
approx.
crank angle (deg.)
0
500
1000
1500
2000
2500
3000
540
600
660
720
780
840
900

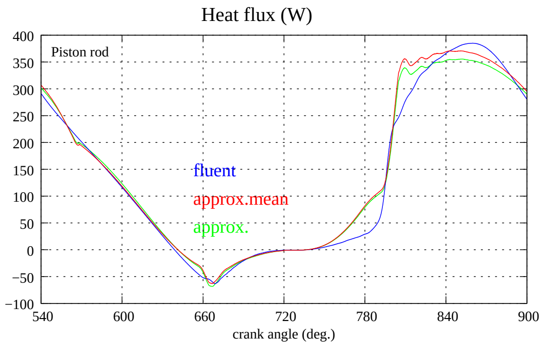

Heat transfer coefficient$[\frac{W}{m^2K}]$
Head
fluent
approx.mean
approx.
crank angle (deg.)
0
500
1000
1500
2000
2500
3000
540
600
660
720
780
840
900

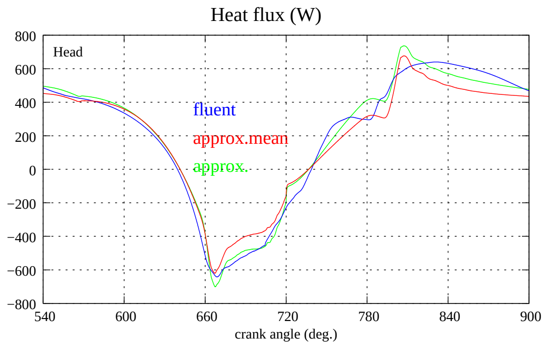

Heat transfer coefficient$[\frac{W}{m^2K}]$
Side wall
fluent
approx.mean
approx.
crank angle (deg.)
0
500
1000
1500
2000
2500
540
600
660
720
780
840
900

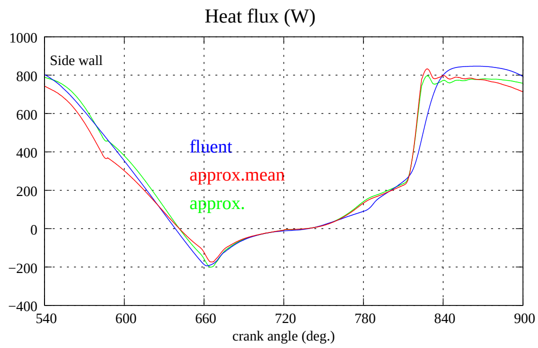
6.35 Methan Case 11

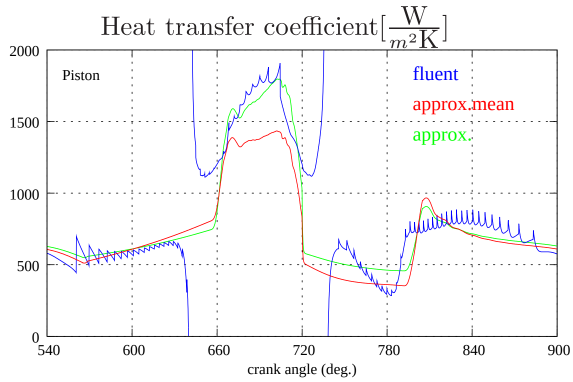


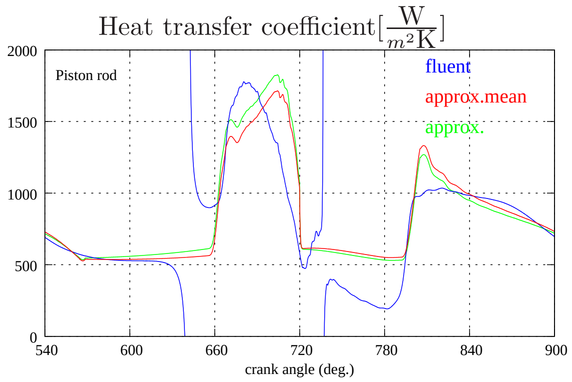


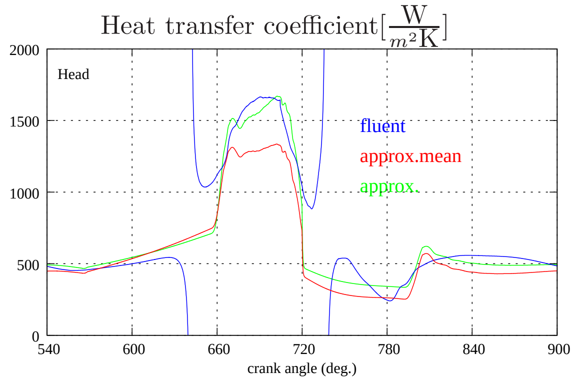


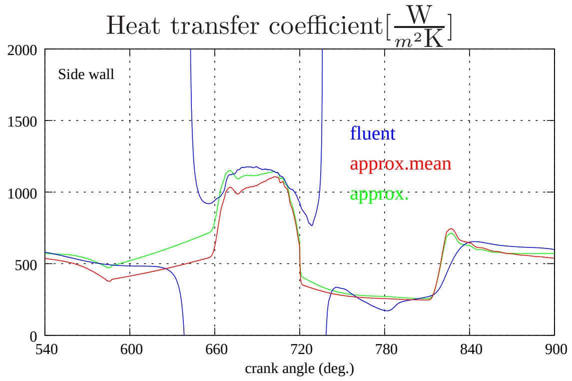





Heat transfer coefficient[$\frac{W}{m^2K}$]
Piston
fluent
approx.mean
approx.
crank angle (deg.)


Heat transfer coefficient[$\frac{W}{m^2K}$]
Piston rod
fluent
approx.mean
approx.
crank angle (deg.)


Heat transfer coefficient[$\frac{W}{m^2K}$]
Head
fluent
approx.mean
approx.
crank angle (deg.)


Heat transfer coefficient[$\frac{W}{m^2K}$]
Side wall
fluent
approx.mean
approx.
crank angle (deg.)