



Library for Calculating Operation Characteristics of Heat Exchangers from VDI Heat Atlas

**FluidLAB
with LibHeatEx
for MATLAB®
and Simulink®**

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Software for the Calculation of the Properties of Heat Exchangers

FluidLAB

LibHeatEx

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0 Package Contents

0.1 Zip file for 32-bit MATLAB®

The following zip file is delivered for your computer running a 32-bit version of MATLAB®.

"CD_FluidLAB_LibHEATEX.zip"

Including the following files:

FluidLAB_LibHEATEX_Setup.exe	- Installation program for the FluidLAB Add-On for use in MATLAB®
LibHEATEX.dll	- Dynamic Link Library for steam and water for use in MATLAB®
FluidLAB_LibHEATEX_Docu_Eng.pdf	- User's Guide

0.2 Zip file for 64-bit MATLAB®

The following zip file is delivered for your computer running a 64-bit version of MATLAB®.

"CD_FluidLAB_LibHEATEX_x64.zip"

Including the following files:

Setup.exe	- Self-extracting and self-installing program for FluidLAB
FluidLAB_LibHEATEX_64_Setup.msi	- Installation program for the FluidLAB Add-On for use in MATLAB®
LibHEATEX.dll	- Dynamic Link Library for steam and water for use in MATLAB®
FluidLAB_LibHEATEX_Docu_Eng.pdf	- User's Guide

1. Property Functions

1.1 Functions

Functional Dependence	Function Name	Call as Function from LibHeatEx DLL	Function
$\Phi_A = f\left(ITYPE, \frac{k \cdot A}{\dot{C}_A}, \frac{\dot{C}_A}{\dot{C}_B}, NSPEC\right)$	Phi_HeatEx	PHI_HeatEx(ITYPE, kaCA, CACB, NSPEC)	Dimensionless temperature changes
$\frac{k \cdot A}{\dot{C}_A} = f\left(ITYPE, \Phi_A, \frac{\dot{C}_A}{\dot{C}_B}, NSPEC\right)$	kaCA_HeatEx	kaCA_HeatEx (ITYPE, PHI, CACB, NSPEC)	Number of transfer units
$\frac{\dot{C}_A}{\dot{C}_B} = f\left(ITYPE, \Phi_A, \frac{k \cdot A}{\dot{C}_A}, NSPEC\right)$	CACB_HeatEx	CACB_HeatEx (ITYPE, PHI, kaCA, NSPEC)	Heat capacity rate ratios

Units: All quantities are dimensionless.

Equations:

Dimensionless temperature changes

$$\Phi = Phi = \frac{t_{H1} - t_{H2}}{t_{H1} - t_{K1}}$$

Determination:

A – heating surface

$$\Phi_A = \Phi_B \cdot \frac{\dot{C}_B}{\dot{C}_A} \quad \Phi_B = \Phi_A \cdot \frac{\dot{C}_A}{\dot{C}_B}$$

c_p – heat capacity

k - heat transfer coefficient

Number of transfer units

$$\frac{k \cdot A}{\dot{C}_A} = \frac{\Delta \vartheta_A}{\Delta \vartheta_{AB}^m} = \frac{k \cdot A}{\dot{C}_B} \cdot \frac{\dot{C}_B}{\dot{C}_A}$$

Indexing:

A – flow A

B – flow B

$$\frac{k \cdot A}{\dot{C}_B} = \frac{\Delta \vartheta_B}{\Delta \vartheta_{AB}^m} = \frac{k \cdot A}{\dot{C}_A} \cdot \frac{\dot{C}_A}{\dot{C}_B}$$

H – heating medium

Ratios of the heat capacity rate

$$\frac{\dot{C}_A}{\dot{C}_B} = \frac{\Delta \vartheta_B}{\Delta \vartheta_A}$$

$$\frac{\dot{C}_B}{\dot{C}_A} = \frac{\Delta \vartheta_A}{\Delta \vartheta_B}$$

K – cooling medium

1 – inlet of A and B

2 – outlet of A and B

\dot{C}_A - heat capacity rate flow A

$$\dot{C}_A = \dot{m}_A \cdot c_{pA}$$

\dot{m} - mass flow

\dot{C}_B - heat capacity rate flow B

$$\dot{C}_B = \dot{m}_B \cdot c_{pB}$$

c_p – isobaric heat capacity

Δt_A - temperature changes flow A

$$\Delta t_A = t_{A1} - t_{A2}$$

Δt_B - temperature changes flow B

$$\Delta t_B = t_{B1} - t_{B2}$$

c_{pA}^m - mean isobaric heat capacity of flow A

$$c_{pA}^m = \frac{h_{A2} - h_{A1}}{t_{A2} - t_{A1}} \quad \text{for } p_A \approx \text{const.}$$

approximation:

$$c_{pA}^m \approx \frac{1}{2} [c_{pA}(t_{A1}) + c_{pA}(t_{A2})]$$

h – specific enthalpy

t – temperature

p – pressure of flow A and flow B

c_{pB}^m - mean isobaric heat capacity of flow B

$$c_{pB}^m = \frac{h_{B2} - h_{B1}}{t_{B2} - t_{B1}} \quad \text{for } p_B \approx \text{const.}$$

approximation:

$$c_{pB}^m \approx \frac{1}{2} [c_{pB}(t_{B1}) + c_{pB}(t_{B2})]$$

1.2 Range of Validity

The LibHeatEx property library has been developed to calculate different heat exchangers, which have been taken from the VDI-Heat Atlas [3].

One of the two streams is referred to as heating medium and the other one as cooling medium. The heating medium transfers thermal energy to the cooling medium.

Thermal losses to the surrounding are neglected, which means that the heat exchanger is calculated adiabatically. The result of the first law of thermodynamics are functional coherences between the dimensionless temperature changes Φ , the number of transfer units $\frac{k \cdot A}{\dot{C}_A}$, which is also referred to as NTU or N , and the ratios of the heat capacity rate

$\frac{\dot{C}_A}{\dot{C}_B}$ or R . The basic functional dependency is $\Phi = \Phi(\frac{k \cdot A}{\dot{C}_A}, \frac{\dot{C}_A}{\dot{C}_B})$. In most cases the

equation cannot be solved for the other two variables. These functions are $\frac{k \cdot A}{\dot{C}_A} = f(\Phi, \frac{\dot{C}_A}{\dot{C}_B})$

and $\frac{\dot{C}_A}{\dot{C}_B} = f(\Phi, \frac{k \cdot A}{\dot{C}_A})$, they therefore have to be calculated iteratively. In order to select the

correct type of the heat exchanger, please use Table 1 of this User's Guide or the help file LibHeatEx.hlp. Each heat exchanger type is assigned to one number, which is specified as the variable I_{TYPE} . This is also the first input parameter for each function in Excel®.

There are also functions with a variable number of tube rows or passes which is indicated by the parameter N_{SPEC} . N_{SPEC} is also given in Table 1 and in the help file LibHeatEx.hlp.

The functional dependencies of flow A with I_{TYPE} and N_{SPEC} are

$$\Phi_A = f(I_{TYPE}, \frac{k \cdot A}{\dot{C}_A}, \frac{\dot{C}_A}{\dot{C}_B}, N_{SPEC}),$$

$$\frac{k \cdot A}{\dot{C}_A} = f(I_{TYPE}, \Phi_A, \frac{\dot{C}_A}{\dot{C}_B}, N_{SPEC}), \text{ and}$$

$$\frac{\dot{C}_A}{\dot{C}_B} = f(I_{TYPE}, \Phi_A, \frac{k \cdot A}{\dot{C}_A}, N_{SPEC}).$$

The dependencies for flow B are

$$\Phi_B = f(I_{TYPE}, \frac{k \cdot A}{\dot{C}_B}, \frac{\dot{C}_B}{\dot{C}_A}, N_{SPEC}),$$

$$\frac{k \cdot A}{\dot{C}_B} = f(I_{TYPE}, \Phi_B, \frac{\dot{C}_B}{\dot{C}_A}, N_{SPEC}), \text{ and}$$

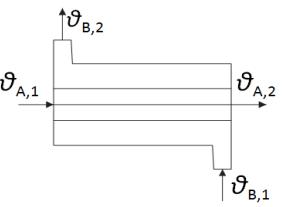
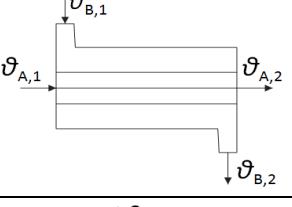
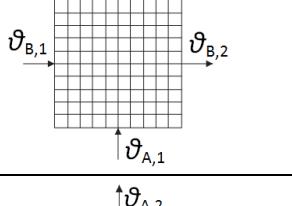
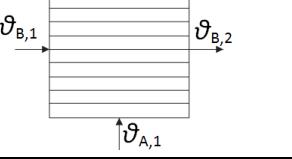
$$\frac{\dot{C}_B}{\dot{C}_A} = f(I_{TYPE}, \Phi_B, \frac{k \cdot A}{\dot{C}_B}, N_{SPEC}).$$

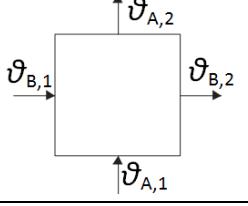
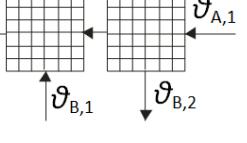
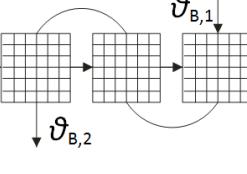
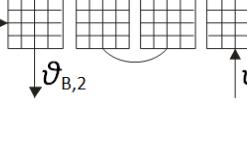
The range of validity for the different parameters are shown in the following Table 1

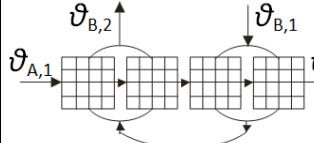
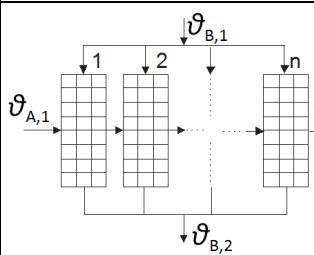
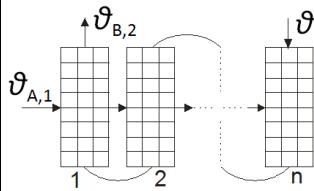
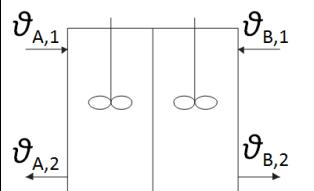
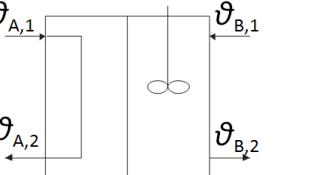
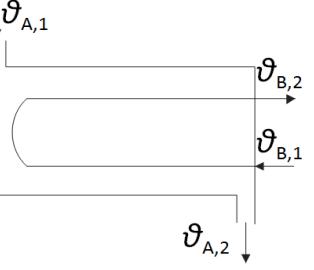
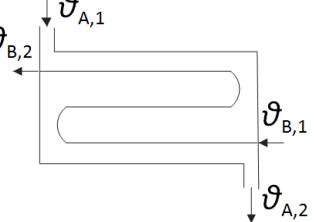
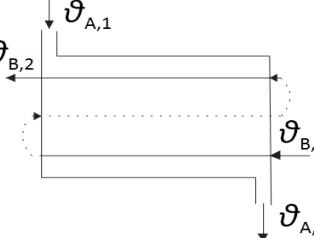
Table 1: Range of validity

Quantities	Range of validity
Dimensionless temperature changes:	$0 \leq \Phi \leq 1$
Number of transfer units:	$0 < kaCA$
Heat capacity rate ratios:	$0 \leq CACB$
Type of Heat Exchanger:	$0 < ITYPE \leq 24$
Number of tube rows or passes:	$0 = NSPEC$ for ITYPE 1-9; 12-19; 21-24 $0 < NSPEC$ for ITYPE 10; 11; 20

Table 2: List of heat exchanger types

I_{TYPE}	Type	Flow arrangement	N_{SPEC}
1	Pure counter current flow $i = A,B$		0
2	Pure cocurrent flow $i = A,B$		0
3	Pure cross-flow $i = A,B$		0
4	Cross-flow with one tube row, laterally mixed on one side		0

I_{TYPE}	Type	Flow arrangement	N_{SPEC}
5	Cross-flow, laterally mixed on both sides $i = A,B$		0
6	Counterdirected countercurrent cross-flow with two tube rows and two passes		0
7	Counterdirected countercurrent cross-flow with three tube rows and three passes		0
8	Counterdirected countercurrent cross-flow with four tube rows and four passes		0

I_{TYPE}	Type	Flow arrangement	N_{SPEC}
9	Counterdirected countercurrent cross-flow with four tube rows and two passes		0
10	Cross-flow with n tube rows and one pass $n = 1, 2, \dots, \infty$		$1, 2, \dots, \infty$
11	Codirected countercurrent cross-flow with n tube rows and n passes $n = 1, 2, \dots, \infty$		$1, 2, \dots, \infty$
12	Two-sided stirred tank $i = A, B$		0
13	One-sided stirred tank		0
14	One shell-side and two tubeside passes $i = A, B$		0
15	One shell-side and three tubeside passes, two countercurrent		0
16	One shell-side and two tubeside passes, both countercurrent		$1, 2, \dots, \infty$

2 Application of FluidLAB in MATLAB®

The FluidLAB Add-In has been developed to calculate heat exchanger characteristics in MATLAB® more conveniently. Within MATLAB® it enables the direct call of functions from the LibHeatEx calculation library.

2.1 Installing FluidLAB including LibHeatEx

This Section describes the installation of FluidLAB including the LibHeatEx library.
After you have downloaded and extracted the zip-file

CD_FluidLAB_LibHeatEx.zip (32 bit version)

or

CD_FluidLAB_LibHeatEx_x64.zip (64 bit version)

you will see the folder

\CD_FluidLAB_LibHeatEx\ (32 bit version)

or

\CD_FluidLAB_LibHeatEx_x64\ (64 bit version)

in your Windows Explorer®, Norton Commander® or other program you are using.

Open this folder by double-clicking on it.

In this folder you will see the following files:

FluidLAB_LibHeatEx_Setup.msi (for 32-bit installation)

FluidLAB_LibHeatEx_64_Setup.msi (for 64-bit installation)

FluidLAB_LibHeatEx_Docu_Eng.pdf

LibHeatEx.dll.

setup.exe

In order to run the installation of FluidLAB including the LibHeatEx calculation library, double-click on the file

setup.exe.

If an error message from C++ appears, please double click the file

FluidLAB_LibHeatEx_Setup.msi (for 32-bit installation)

or

FluidLAB_LibHeatEx_64_Setup.msi (for 64-bit installation)

for the installation.

In the following dialog box, "Destination Location", the default path offered automatically for the installation of FluidLAB is

C:\Program Files (x86)\FluidLAB\LibHeatEx\ (for 32-bit installation)

or

C:\Program Files\FluidLAB\LibHeatEx\ (for 64-bit installation).

But, this offered path could cause problems with user rights and thus prevent the installation. Therefore, an example path

D:\Example\

is used in the following explanations, which is located on a drive that does not contain the Windows installation.

By clicking the "Browse..." button, you can change the installation directory before installation (see Figure 2.1).

Note:

The product name "Lib_____" in the following Figures stands for the Library you are installing or have installed. In this case it is the LibHeatEx library.

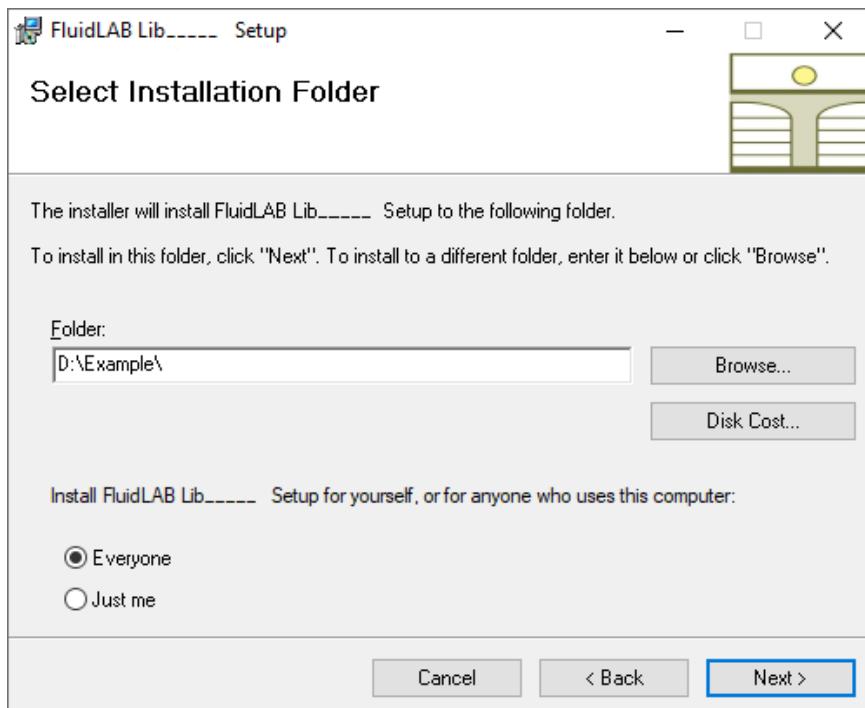


Figure 2.1: "Destination Location"

After you have chosen your desired installation path leave this window by clicking the "Next >" button.

The dialog window "Start Installation" pops up.

Click the "Next >" button to continue installation. The FluidLAB files are now being copied into the created directory on your hard drive.

Click the "Finish >" button in the following window to complete installation.

The installation program has copied the following files into the chosen \LibHeatEx\ directory:

LibHeatEx.dll,

LC.dll,

libifcoremd.dll,

libiomp5md.dll,

Libmmd.dll.

In addition, there are specific files for all functions

*.mexw32 (for 32-bit version)

or

*.mexw64 (for 64-bit version).

The names of these functions are listed in Section 1.

Note:

To use the FluidLAB library LibHeatEx you can simply copy all delivered files into your MATLAB project folder or link the installation path to your project. How to add a path to your MATLAB project is described below in Section 2.4.

Now, you have to overwrite the file "LibHeatEx.dll" in your created \LibHeatEx\ directory with the file of the same name provided in the delivered CD. The directory is either

C:\Program Files (x86)\FluidLAB\LibHeatEx (for 32-bit installation)

or

C:\Program Files\FluidLAB\LibHeatEx (for 64-bit installation)

or the directory you have specified, e.g.

D:\Example\.

Now, the LibHeatEx calculation functions are available in MATLAB®.

2.2 Licensing the LibHeatEx Calculation Library

The licensing procedure must be carried out when the prompt message appears. In this case, you will see the "License Information" window for LibHeatEx (see Figure below).

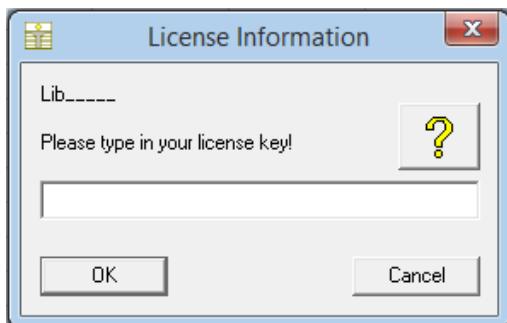


Figure 2.2: "License Information" window

Here you are asked to type in the license key. If you do not have this, or have any questions, you will find contact information on the "Content" page of this User's Guide or by clicking the yellow question mark in the "License Information" window. Then the following window will appear:

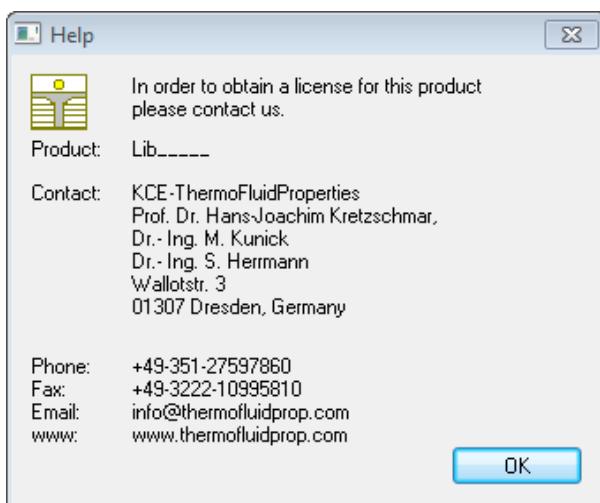


Figure 2.3: "Help" window

If you do not enter a valid license it is still possible to use MATLAB® by clicking "Cancel". In this case, the LibHeatEx property library will display the result "-11111111" for every calculation.

The "License Information" window will appear every time you use FluidLAB LibHeatEx until you enter a license code to complete registration. If you decide not to use FluidLAB LibHeatEx, you can uninstall the program following the instructions given in section 2.5 of this User's Guide.

2.3 Example Calculation

Now we will calculate, step by step, an example of a function to show how to use FluidLAB mit the LibHeatEx library.

In the following we use the recommended folder D:\Example\.

Note:

Of course, any other folder in which the LibHeatEx files are stored will also work, for example your current MATLAB® project directory.

Please carry out the following instructions:

- Start MATLAB® and choose your FluidLAB folder with the library LibHeatEx files in the upper directory bar of MATLAB® (shown in Figure 2.4, marked with 1).
- Now we create a new MATLAB® script file to write our example calculation script. Click on the symbol shown in Figure 2.4, marked with 2.
- We have to save the file and give it a name. In our example we use "example.m" as the file name. To save click on the symbol shown in Figure 2.4, marked with 3.
- Type the following lines into the "example.m" window:
The code is also shown in Figure 2.4, marked with 4.

Text to be written:	Explanation:
% PHI_HeatEx.m	file name as comment
%%	paragraph separation
I_Type=1; % pressure in bar	Input values for the variables
kaCa=1; % temperature in °C	pressure, temperature and
CACB=0.5; % vapor fraction	vapor fraction
NSPEC=0	
%%	paragraph separation
PHI=PHI_HeatEx(I_Type, kaCa, CACB, NSPEC)	function call
%%	paragraph separation

- To calculate the example press F5 on your keyboard or click on the symbol shown in Figure 2.4, marked with 5.
- In the "Command Window" you will see the result "PHI = 0.5647", marked with 6 in Figure 2.4. The corresponding unit is kJ/kg (see table of the property functions in Chapter 1).

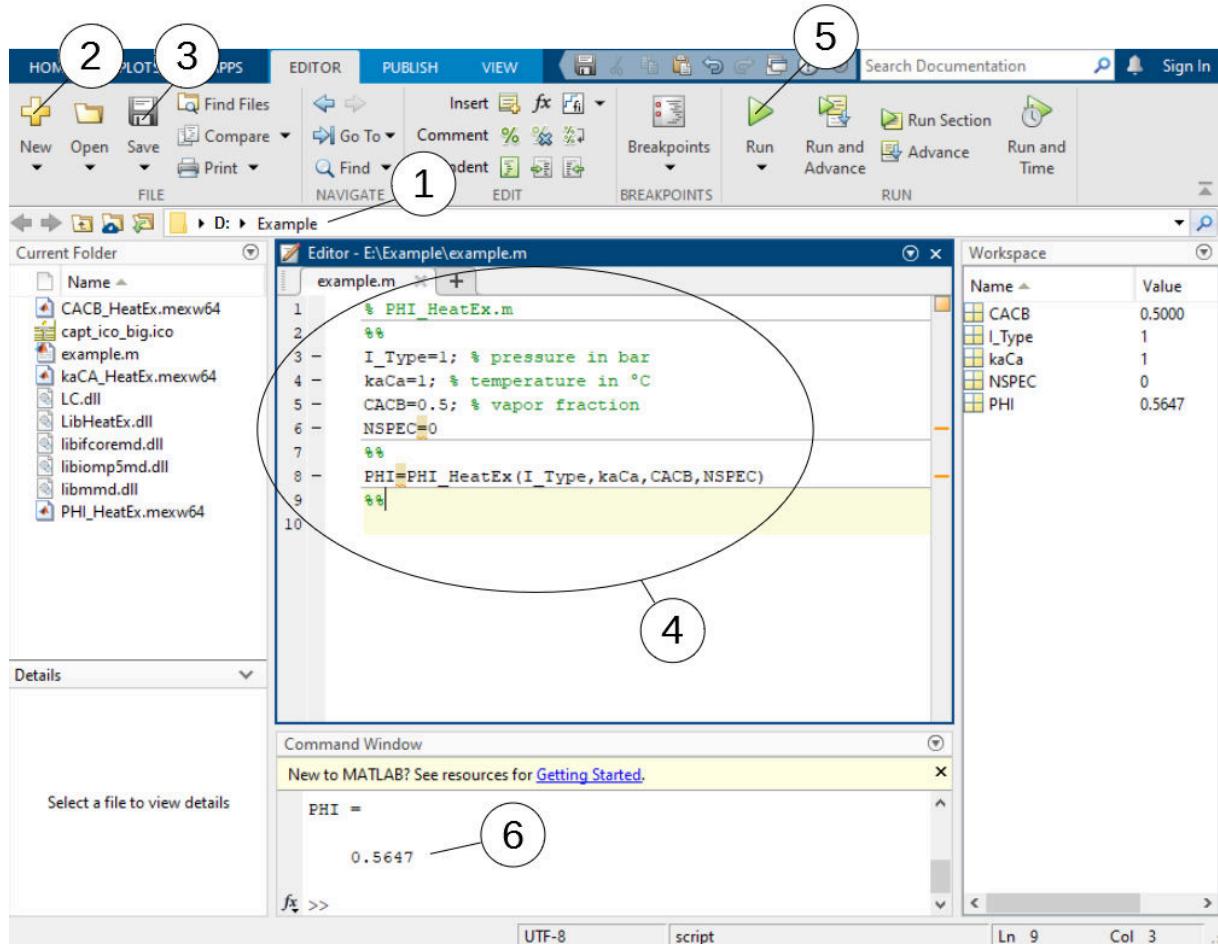


Figure 2.4: Example calculation in MATLAB®

- Remarks:

- The program interprets the first line which starts with " %" to be a data description in "Current Directory"
- Paragraph separations which are mandatory are being realised through " %%". By this, declaration of variables and calculation instructions are also being separated.
- The words which are printed in green, start with " %" and stand behind the variables are comments. In fact they are not necessary but they are reasonable for your overview and comprehensibility.
- You have to leave out the semicolons behind the numerical values if you wish to see the result for h and the input parameters as well.

The values of the function parameters in their corresponding units stand for:

- $\frac{k \cdot A}{\dot{C}_A} = 1.00$ and $\frac{\dot{C}_A}{\dot{C}_B} = 0.5$
- I_{TYPE} and N_{SPEC} can be obtained from Table 1.
- Type of heat exchanger: $I_{TYPE} = 1$
- Number of tube rows or passes: $N_{SPEC} = 0$

2.4 Using FluidLAB with SIMULINK

To use the functions of FluidLAB with the simulation program SIMULINK you have to start SIMULINK in MATLAB® by clicking on Simulink in the upper menu bar shown in Figure 2.5.

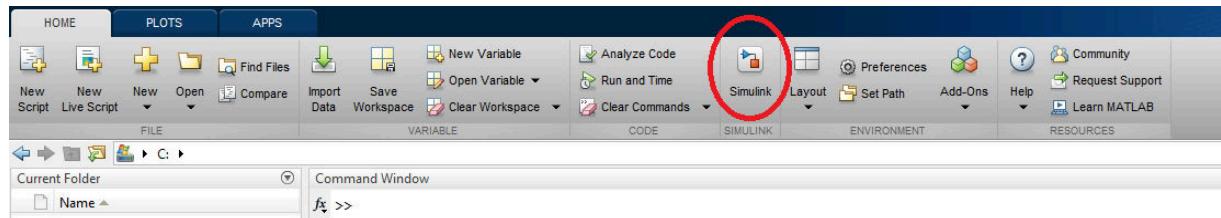


Figure 2.5: Starting Simulink

Then choose a blank model or a simulation in which you would like to use FluidLAB. Now you need to add a MATLAB function block that you can find in the library browser shown in Figure 2.6.

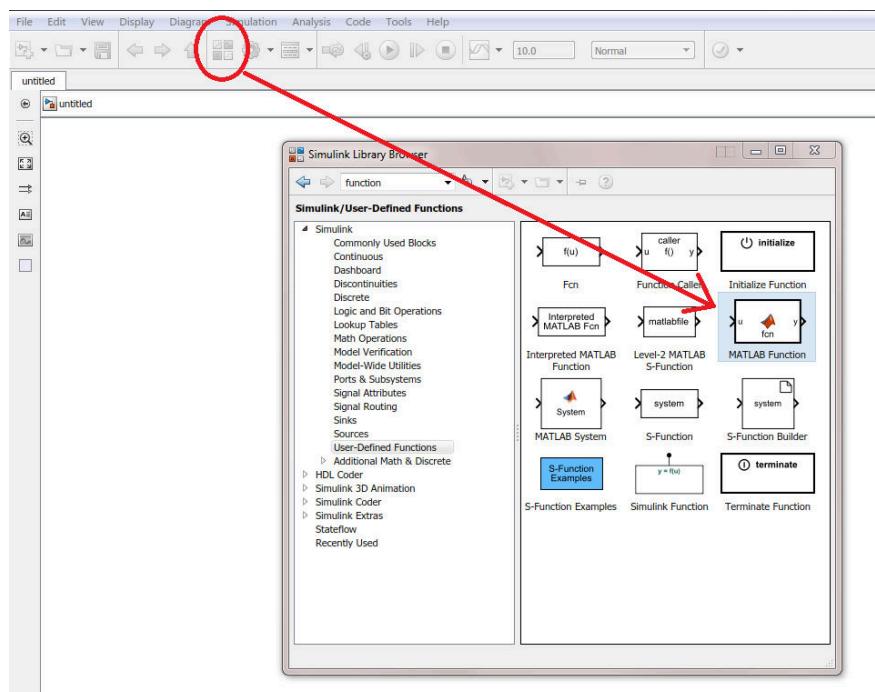


Figure 2.6: Simulink library browser and choosing a MATLAB Function

By dragging and dropping you can drag a Simulink block in your model. The function needs inputs and output that you can find in the Simulink library browser under sources and sinks. For this example constants were taken for the inputs and a display block were taken for outputting. The inputs and outputs in Simulink have to match with the number of input and output values of the FluidLAB-function you want to use.

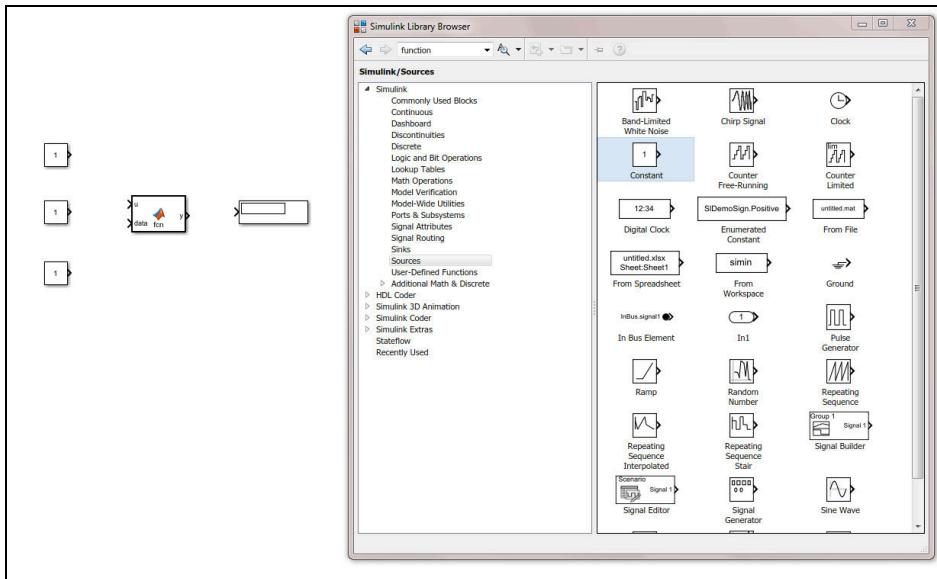


Figure 2.7: Inputs and outputs of the example

Now you have to link inputs and outputs to the MATLAB function block. By pressing and holding the left mouse button on the arrow of a block, you can draw a line and drag it to the MATLAB function block. With this method you can link all blocks together.

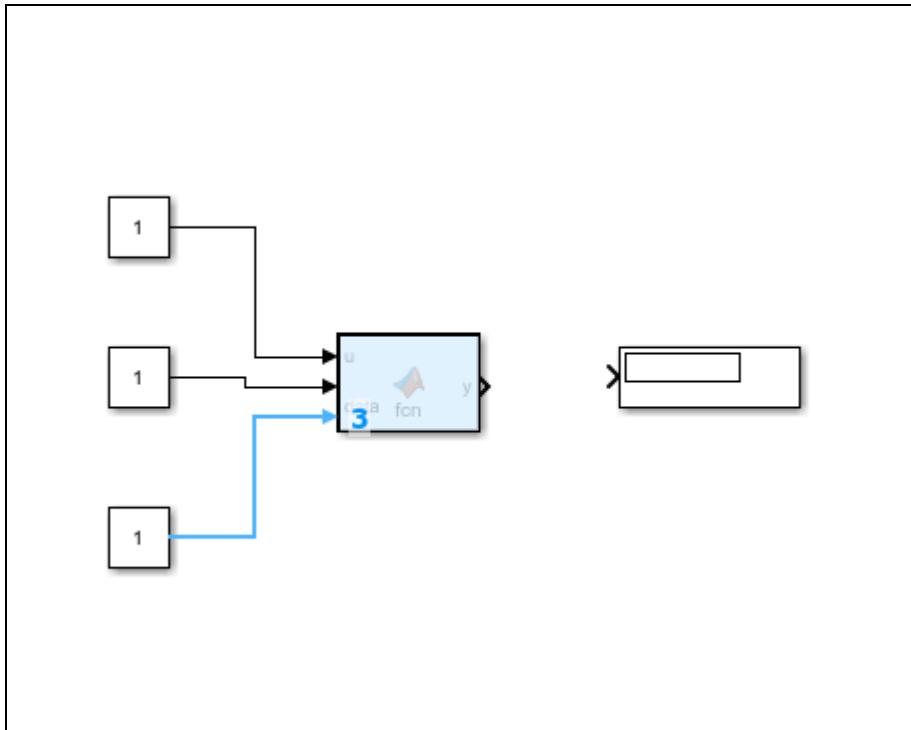


Figure 2.8: Linking blocks in Simulink

You can define the value of a constant block by double-click on them. If you want to calculate the example use the values you can find in Section 2.3. With a double-click on the MATLAB function block you can define the function in MATLAB®. The following source code is for the example calculation and the table below describes the source code closer.

You can adapt these few lines to call all other function of FluidLAB:

```
function PHI = fcn(I_Type, kaCa, CACB, NSPEC)
coder.extrinsic('addpath');
coder.extrinsic('PHI_HeatEx');
addpath('D:\Example\' );
PHI = coder.nullcopy(zeros(size(1)));
PHI = PHI_HeatEx(I_Type,kaCa,CACB,NSPEC);
```

Matlab source code	Explanation
function PHI = fcn(I_Type, kaCa, CACB, NSPEC)	function header, you can define the function name and the inputs
coder.extrinsic('addpath')	necessary to add a path
coder.extrinsic('PHI_HeatEx');	Choose the function name of the FluidLAB function
addpath('D:\Example\');	Add the installation path of FluidLAB
PHI =	Declaration of the output value PHI and filling it with zeros
coder.nullcopy(zeros(size(1)));	
PHI =	
PHI_HeatEx(I_Type,kaCa,CACB,NSPEC);	Linking the FluidLAB function to the MATLAB function block

You can copy and paste the sourcecode in MATLAB® or write it into the MATLAB® editor. The simulation will start by clicking the run button in Matlab or Simulink and you can see the example in the display block of the simulation which is shown in Figure 2.23.

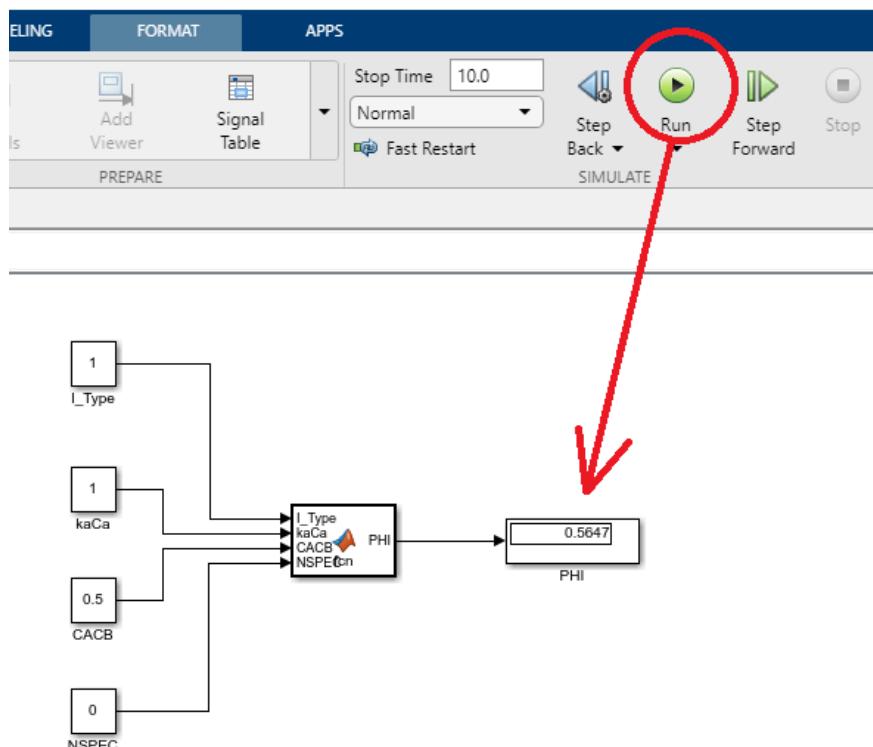


Figure 2.9: Starting the simulation and result of the calculation

Your result is may an other than shown in Figure 2.9. If you want to calculate the example please use the values from section 2.3.

2.5 Removing FluidLAB including LibHeatEx

- To remove the LibHeatEx property library from your hard disk drive in Windows®, click "Start" in the Windows® task bar, select "Settings" and click "Control Panel".
- Now double-click on "Add or Remove Programs".
- In the list box of the "Add or Remove Programs" window that appears select "FluidLAB LibHeatEx" by clicking on it and click the "Change/Remove" button.
- In the following dialog box click "Automatic" and thereafter click the "Next>" button.
- Confirm the following menu "Perform Uninstall" by clicking the "Finish" button.
- Finally, close the windows "Add or Remove Programs" and "Control Panel" windows.
- Now, FluidLAB has been removed.

3. Program Documentation

Dimensionless Temperature Changes: $\phi = f\left(ITYPE, \frac{k \cdot A}{C_A}, \frac{\dot{C}_A}{\dot{C}_B}, NSPEC \right)$

Function Name:	Phi_HeatEx
Declaration for DLL:	PHI_HeatEx (ITYPE,kaCA,CACB,NSPEC)
Fortran 77 Subprogram:	<pre>REAL*8 FUNCTION PHI_HeatEx (ITYPE, kaCA, CACB, NSPEC) REAL*8 kaCA, CACB INTEGER*4 ITYPE, NSPEC</pre>

Input values

Type of heat exchanger	<i>ITYPE</i>	
Number of transfer units	$kaCA = \frac{k \cdot A}{\dot{C}_A}$	A – heating surface <i>k</i> - heat transfer coefficient
Heat capacity rate ratios	$CACB = \frac{\dot{C}_A}{\dot{C}_B}$	\dot{C}_A - heat capacity rate ratios stream A \dot{C}_B - heat capacity rate ratios stream B
Number of tube rows or passes	<i>NSPEC</i>	

Result

PHI_HeatEx – Dimensionless temperature changes

$$\phi = Phi = \frac{t_{A1} - t_{A2}}{t_{A1} - t_{B1}} = \frac{\Delta \vartheta_A}{\Delta \vartheta_{AB}^{\max}}$$

A – stream A	1 – Inlet of A and B
B – stream B	2 – Outlet of A and B

Range of Validity

Number of transfer units:	$0 < kaCA$
Heat capacity rate ratios:	$0 \leq CACB$
Type of heat exchanger:	$0 < ITYPE \leq 24$
Number of tube rows or passes:	$0 = NSPEC$ for <i>ITYPE</i> 1-9; 12-19; 21-24 $0 < NSPEC$ for <i>ITYPE</i> 10; 11; 20

Results for wrong input values

PHI_HeatEx = -9999

References: [1]

$$\text{Number of Transfer Units: } \frac{k \cdot A}{\dot{C}_A} = f\left(ITYPE, \Phi, \frac{\dot{C}_A}{\dot{C}_B}, NSPEC\right)$$

Function Name: **kaCA_HeatEx**
 Declaration for DLL: **kaCA_HeatEx (ITYPE,PHI,CACB,NSPEC)**
 Fortran 77 Subprogram:
REAL*8 FUNCTION kaCA_HeatEx(ITYPE,PHI,CACB,NSPEC)
REAL*8 PHI, CACB
INTEGER*4 ITYPE, NSPEC

Input values

Type of heat exchanger	<i>ITYPE</i>	
Dimensionless temperature changes	$\Phi = Phi = \frac{t_{A1} - t_{A2}}{t_{A1} - t_{B1}} = \frac{\Delta \vartheta_A}{\Delta \vartheta_{AB}^{\max}}$	A – stream A B – stream B 1 – Inlet of A and B 2 – Outlet of A and B
Heat capacity rate ratios	$CACB = \frac{\dot{C}_A}{\dot{C}_B}$	\dot{C}_A - heat capacity rate ratios stream A \dot{C}_B - heat capacity rate ratios stream B
Number of tube rows or passes	<i>NSPEC</i>	

Result

kaCA_HeatEx – Number of transfer units

$$kaCA = \frac{k \cdot A}{\dot{C}_A}$$

A – heating surface
k – heat transfer coefficient

Range of Validity

Dimensionless temperature changes:	$0 \leq Phi \leq 1$
Heat capacity rate ratios:	$0 \leq CACB$
Type of heat exchanger:	$0 < ITYPE \leq 24$
Number of tube rows or passes:	$0 = NSPEC$ for ITYPE 1-9; 12-19; 21-24 $0 < NSPEC$ for ITYPE 10; 11; 20

Results for wrong input values

kaCA_HeatEx = -9999

kaCA_HeatEx = -1 no result at iteration.

References: [1]

$$\text{Heat Capacity Rate Ratios: } \frac{\dot{C}_A}{\dot{C}_B} = f\left(ITYPE, \Phi, \frac{k \cdot A}{\dot{C}_A}, NSPEC \right)$$

Function Name:

CACB_HeatEx

Declaration for DLL:

CACB_HeatEx (ITYPE,PHI, kaCA,NSPEC)

Fortran 77 Subprogram:

```
REAL*8 FUNCTION
CACB_HeatEx (ITYPE,PHI,kaCA,NSPEC)
REAL*8 PHI, kaCA
INTEGER*4 ITYPE, NSPEC
```

Input values

Type of heat exchanger *ITYPE*

Dimensionless temperature changes

$$\Phi = Phi = \frac{t_{A1} - t_{A2}}{t_{A1} - t_{B1}} = \frac{\Delta \vartheta_A}{\Delta \vartheta_{AB}^{\max}}$$

A – stream A

B – stream B

1 – Inlet of A and B

2 – Outlet of A and B

Number of transfer units

$$kaCA = \frac{k \cdot A}{\dot{C}_A}$$

A – heating surface

k - heat transfer coefficient

Number of tube rows or passes *NSPEC*

Result

CACB_HeatEx – Heat capacity rate ratios

$$CACB = \frac{\dot{C}_A}{\dot{C}_B} = \frac{\Delta t_B}{\Delta t_A}$$

\dot{C}_A - heat capacity rate ratios stream A
 \dot{C}_B - heat capacity rate ratios stream B

Range of Validity

Dimensionless temperature changes: $0 \leq Phi \leq 1$

Number of transfer units: $0 < kaCA$

Type of Heat Exchanger: $0 < ITYPE \leq 24$

Number of tube rows or passes: $0 = NSPEC$ for ITYPE 1-9; 12-19; 21-24

$0 < NSPEC$ for ITYPE 10; 11; 20

Results for wrong input values

CACB_HeatEx = -9999

CACB_HeatEx = -1 no result at iteration.

References: [1]

Property Libraries for Calculating Heat Cycles, Boilers, Turbines and Refrigerators

Water and Steam

Library LibIF97

- Industrial Formulation IAPWS-IF97 (Revision 2007)
- Supplementary Standards IAPWS-IF97-S01, -S03rev, -S04, and -S05
- IAPWS Revised Advisory Note No. 3 on Thermo-dynamic Derivatives (2008)

Library LibIF97_META

- Industrial Formulation IAPWS-IF97 (Revision 2007) for metastable steam

Humid Combustion Gas Mixtures

Library LibHuGas

Model: Ideal mixture of the real fluids:
 CO_2 - Span, Wagner H_2O - IAPWS-95
 O_2 - Schmidt, Wagner N_2 - Span et al.
Ar - Tegeler et al.
and of the ideal gases:
 SO_2 , CO , Ne
(Scientific Formulation of Bücker et al.)

Consideration of:

- Dissociation from VDI 4670
- Poynting effect

Humid Air

Library LibHuAir

Model: Ideal mixture of the real fluids:
Dry air from Lemmon et al.
Steam, water and ice from IAPWS-IF97 and IAPWS-06

Consideration of:

- Condensation and freezing of steam
- Dissociation from VDI 4670
- Poynting effect from ASHRAE RP-1485

Extremely Fast Property Calculations

Spline-Based Table Look-up Method (SBTL)

Library LibSBTL_IF97

Library LibSBTL_95

Library LibSBTL_HuAir

For steam, water, humid air, carbon dioxide and other fluids and mixtures according IAPWS Guideline 2015 for Computational Fluid Dynamics (CFD), real-time and non-stationary simulations

Carbon Dioxide Including Dry Ice

Library LibCO2

Formulation of Span and Wagner (1996)

Seawater

Library LibSeaWa

IAPWS Industrial Formulation 2013

Ice

Library LibICE

Ice from IAPWS-06, Melting and sublimation pressures from IAPWS-08, Water from IAPWS-IF97, Steam from IAPWS-95 and -IF97

Ideal Gas Mixtures

Library LibIdGasMix

Model: Ideal mixture of the ideal gases:

Ar	NO	He	Propylene
Ne	H_2O	F_2	Propane
N_2	SO_2	NH_3	Iso-Butane
O_2	H_2	Methane	n-Butane
CO	H_2S	Ethane	Benzene
CO_2	OH	Ethylene	Methanol
Air			

Consideration of:

- Dissociation from the VDI Guideline 4670

Library LibIDGAS

Model: Ideal gas mixture from VDI Guideline 4670

Consideration of:

- Dissociation from the VDI Guideline 4670

Humid Air

Library ASHRAE LibHuAirProp

Model: Virial equation from ASHRAE Report RP-1485 for real mixture of the real fluids:

- Dry air
- Steam

Consideration of:

- Enhancement of the partial saturation pressure of water vapor at elevated total pressures

www.ashrae.org/bookstore

Refrigerants

Ammonia

Library LibNH3

Formulation of Tillner-Roth et al. (1993)

R134a

Library LibR134a

Formulation of Tillner-Roth and Baehr (1994)

Iso-Butane

Library LibButane_Iso

Formulation of Bücker and Wagner (2006)

n-Butane

Library LibButane_n

Formulation of Bücker and Wagner (2006)

Mixtures for Absorption Processes

Ammonia/Water Mixtures

Library LibAmWa

IAPWS Guideline 2001 of Tillner-Roth and Friend (1998)

Helmholtz energy equation for the mixing term (also useable for calculating the Kalina Cycle)

Water/Lithium Bromide Mixtures

Library LibWaLi

Formulation of Kim and Infante Ferreira (2004)

Gibbs energy equation for the mixing term

Liquid Coolants

Liquid Secondary Refrigerants

Library LibSecRef

Liquid solutions of water with

$\text{C}_2\text{H}_6\text{O}_2$	Ethylene glycol
$\text{C}_3\text{H}_8\text{O}_2$	Propylene glycol
$\text{C}_2\text{H}_5\text{OH}$	Ethanol
CH_3OH	Methanol
$\text{C}_3\text{H}_8\text{O}_3$	Glycerol
K_2CO_3	Potassium carbonate
CaCl_2	Calcium chloride
MgCl_2	Magnesium chloride
NaCl	Sodium chloride
$\text{C}_2\text{H}_3\text{KO}_2$	Potassium acetate
CHKO_2	Potassium formate
LiCl	Lithium chloride
NH_3	Ammonia

Formulation of the International Institute of Refrigeration (IIR 2010)

Ethanol

Library LibC2H5OH

Formulation of Schroeder et al. (2014)

Methanol

Library LibCH3OH

Formulation of de Reuck and Craven (1993)

Propane

Library LibPropane

Formulation of Lemmon et al. (2009)

Siloxanes as ORC Working Fluids

Octamethylcyclotetrasiloxane $C_8H_{24}O_4Si_4$ Library LibD4

Decamethylcyclopentasiloxane $C_{10}H_{30}O_5Si_5$ Library LibD5

Tetradecamethylhexasiloxane $C_{14}H_{42}O_5Si_6$ Library LibMD4M

Hexamethyldisiloxane $C_6H_{18}OSi_2$ Library LibMM

Formulation of Colonna et al. (2006)

Dodecamethylcyclohexasiloxane $C_{12}H_{36}O_6Si_6$ Library LibD6

Decamethyltetrasiloxane $C_{10}H_{30}O_3Si_4$ Library LibMD2M

Dodecamethylpentasiloxane $C_{12}H_{36}O_4Si_5$ Library LibMD3M

Octamethyltrisiloxane $C_8H_{24}O_2Si_3$ Library LibMDM

Formulation of Colonna et al. (2008)

Nitrogen and Oxygen

Libraries

LibN2 and LibO2

Formulations of Span et al. (2000) and Schmidt and Wagner (1985)

Hydrogen

Library LibH2

Formulation of Leachman et al. (2009)

Helium

Library LibHe

Formulation of Arp et al. (1998)

Hydrocarbons

Decane $C_{10}H_{22}$ Library LibC10H22

Isopentane C_5H_{12} Library LibC5H12_Iso

Neopentane C_5H_{12} Library LibC5H12_Neo

Isohexane C_6H_{14} Library LibC6H14

Toluene C_7H_8 Library LibC7H8

Formulation of Lemmon and Span (2006)

Further Fluids

Carbon monoxide CO Library LibCO

Carbonyl sulfide COS Library LibCOS

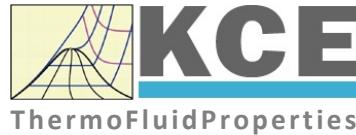
Hydrogen sulfide H_2S Library LibH2S

Nitrous oxide N_2O Library LibN2O

Sulfur dioxide SO_2 Library LibSO2

Acetone C_3H_6O Library LibC3H6O

Formulation of Lemmon and Span (2006)



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01307 Dresden, Germany

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Email: info@thermofluidprop.com

Phone: +49-351-27597860

Mobile: +49-172-7914607

Fax: +49-3222-1095810

The following thermodynamic and transport properties can be calculated^a:

Thermodynamic Properties

- Vapor pressure p_s
- Saturation temperature T_s
- Density ρ
- Specific volume v
- Enthalpy h
- Internal energy u
- Entropy s
- Exergy e
- Isobaric heat capacity c_p
- Isochoric heat capacity c_v
- Isentropic exponent κ
- Speed of sound w
- Surface tension σ

Transport Properties

- Dynamic viscosity η
- Kinematic viscosity ν
- Thermal conductivity λ
- Prandtl number Pr
- Thermal diffusivity a

Backward Functions

- $T, v, s(p,h)$
- $T, v, h(p,s)$
- $p, T, v(h,s)$
- $p, T(v,h)$
- $p, T(v,u)$

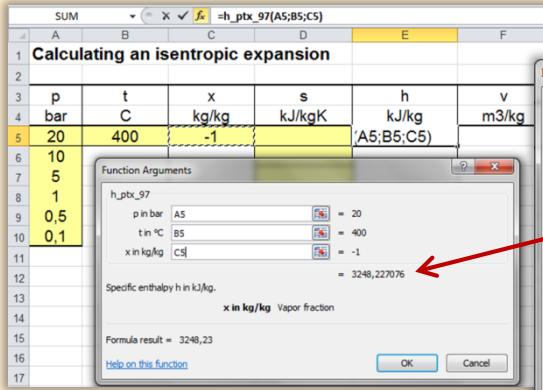
Thermodynamic Derivatives

- Partial derivatives used in process modeling can be calculated.

^a Not all of these property functions are available in all property libraries.

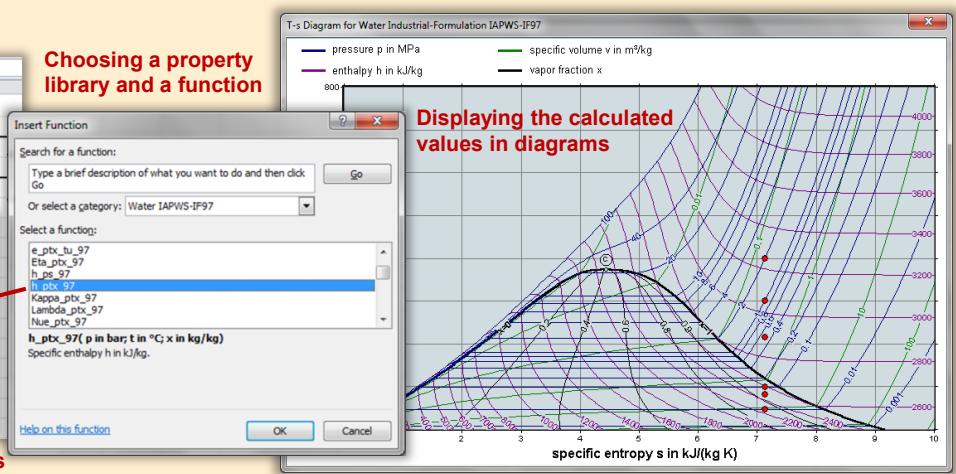
Property Software for Calculating Heat Cycles, Boilers, Turbines and Refrigerators

Add-In FluidEXL Graphics for Excel®



Menu for the input of given property values

Choosing a property library and a function

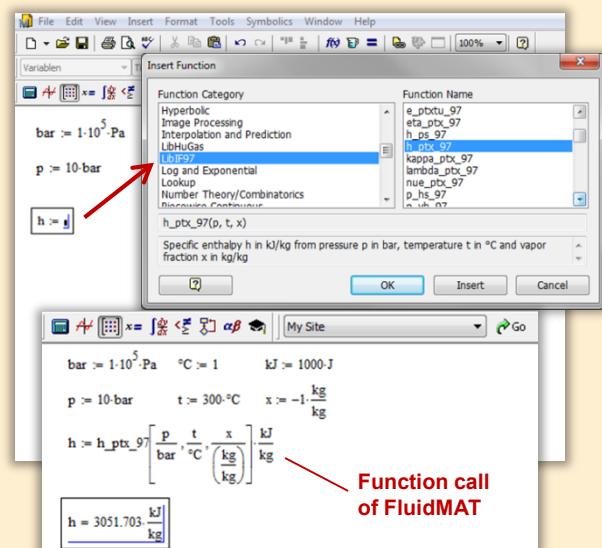


Displaying the calculated values in diagrams

Add-On FluidMAT for Mathcad®

Add-On FluidPRIME for Mathcad Prime®

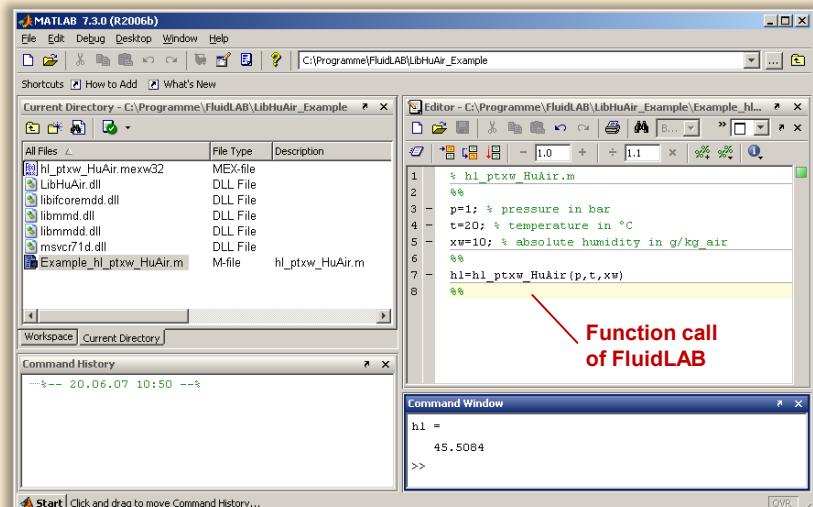
The property libraries can be used in Mathcad® and Mathcad Prime®.



Function call of FluidMAT

Add-On FluidLAB for MATLAB® and SIMULINK®

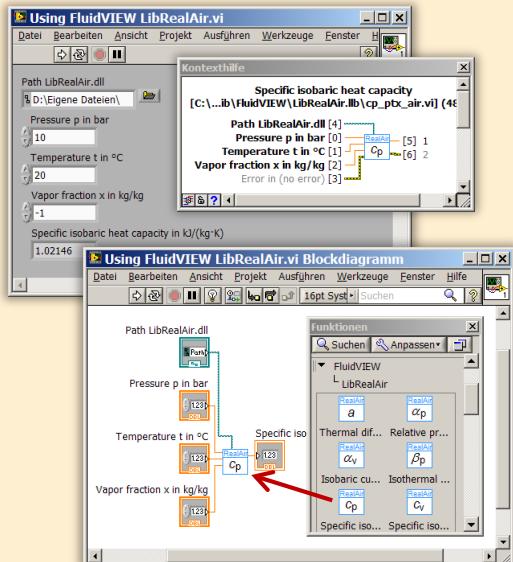
Using the Add-In FluidLAB the property functions can be called in MATLAB® and SIMULINK®.



Function call of FluidLAB

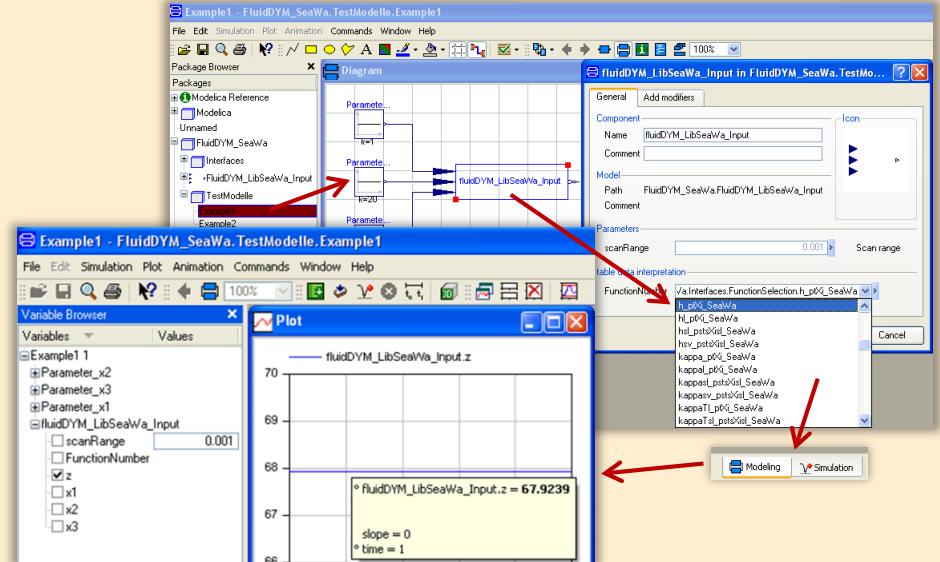
Add-On FluidVIEW for LabVIEW™

The property functions can be calculated in LabVIEW™.

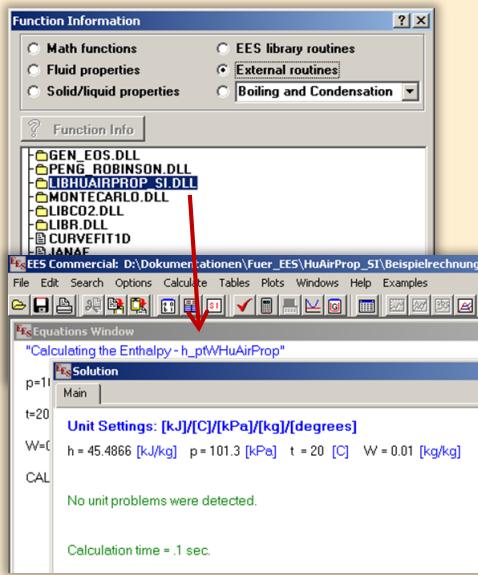


Add-On FluidDYM for DYMOLA® (Modelica) and SimulationX®

The property functions can be called in DYMOLA® and SimulationX®.



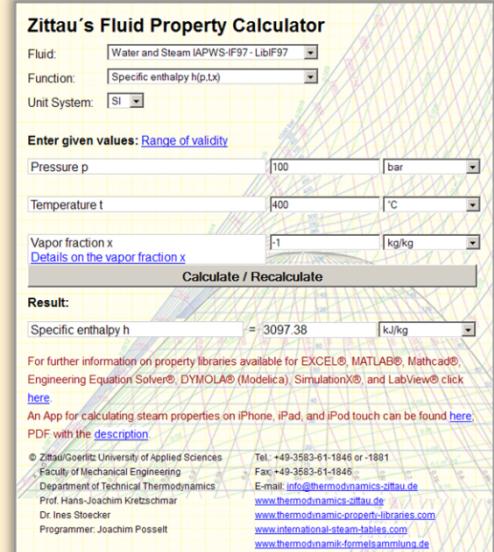
Add-On FluidEES for Engineering Equation Solver®



App International Steam Tables for iPhone, iPad, iPod touch, Android Smartphones and Tablets



Online Property Calculator at www.thermofluidprop.com

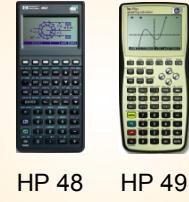


Property Software for Pocket Calculators

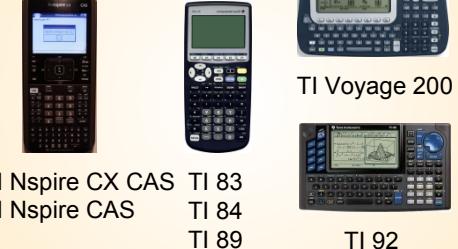
FluidCasio



FluidHP



FluidTI



For more information please contact:



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Mobile: +49-172-7914607
Fax: +49-3222-1095810

The following thermodynamic and transport properties^a can be calculated in Excel®, MATLAB®, Mathcad®, Engineering Equation Solver® (EES), DYMOLA® (Modelica), SimulationX® and LabVIEW™:

Thermodynamic Properties

- Vapor pressure p_s
- Saturation temperature T_s
- Density ρ
- Specific volume v
- Enthalpy h
- Internal energy u
- Entropy s
- Exergy e
- Isobaric heat capacity c_p
- Isochoric heat capacity c_v
- Isentropic exponent κ
- Speed of sound w
- Surface tension σ

Transport Properties

- Dynamic viscosity η
- Kinematic viscosity ν
- Thermal conductivity λ
- Prandtl number Pr
- Thermal diffusivity a

Backward Functions

- $T, v, s (p,h)$
- $T, v, h (p,s)$
- $p, T, v (h,s)$
- $p, T (v,h)$
- $p, T (v,u)$

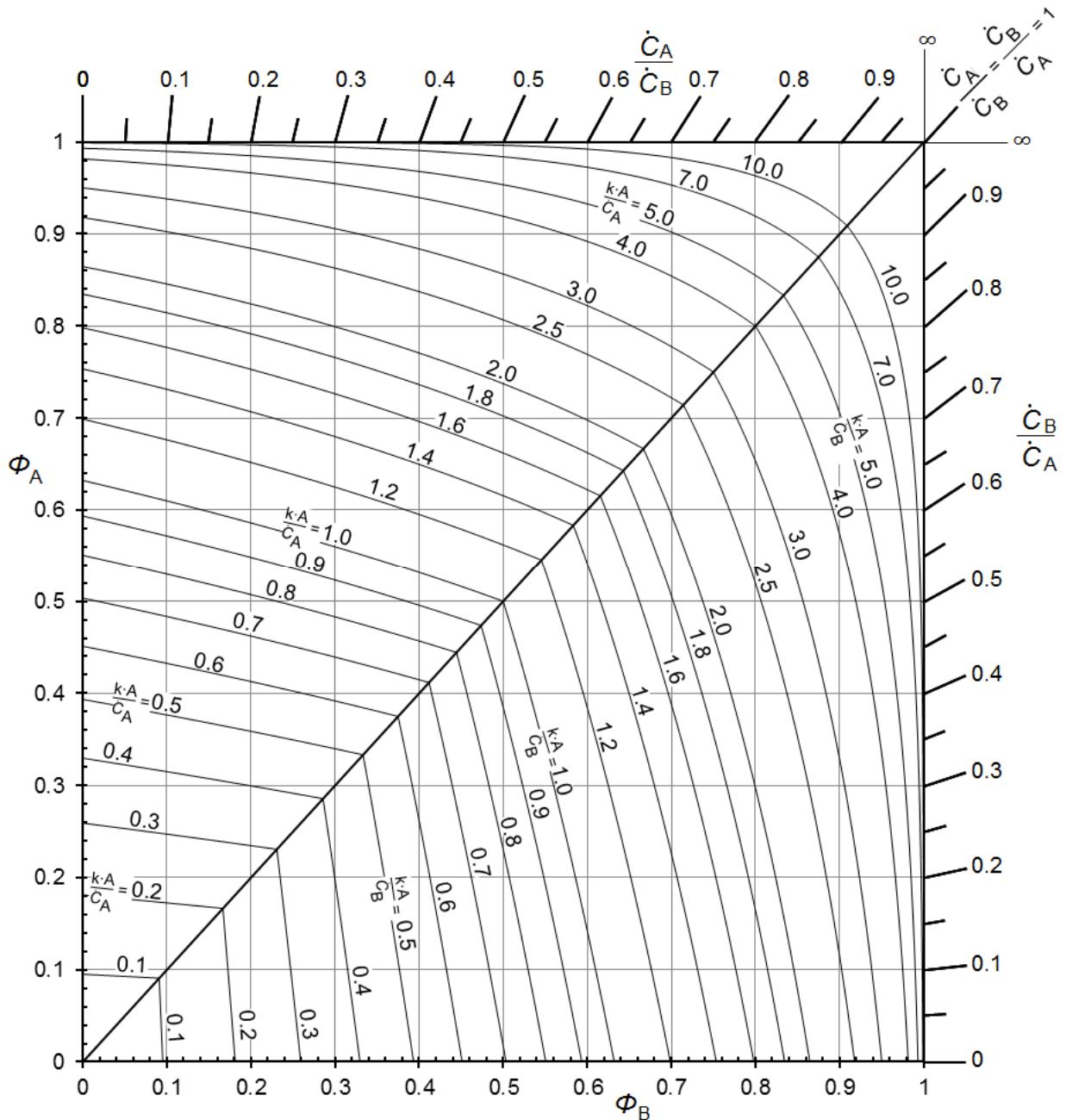
Thermodynamic Derivatives

- Partial derivatives used in process modeling can be calculated.

^a Not all of these property functions are available in all property libraries.

4. Diagrams of Dimensionless Temperature Changes

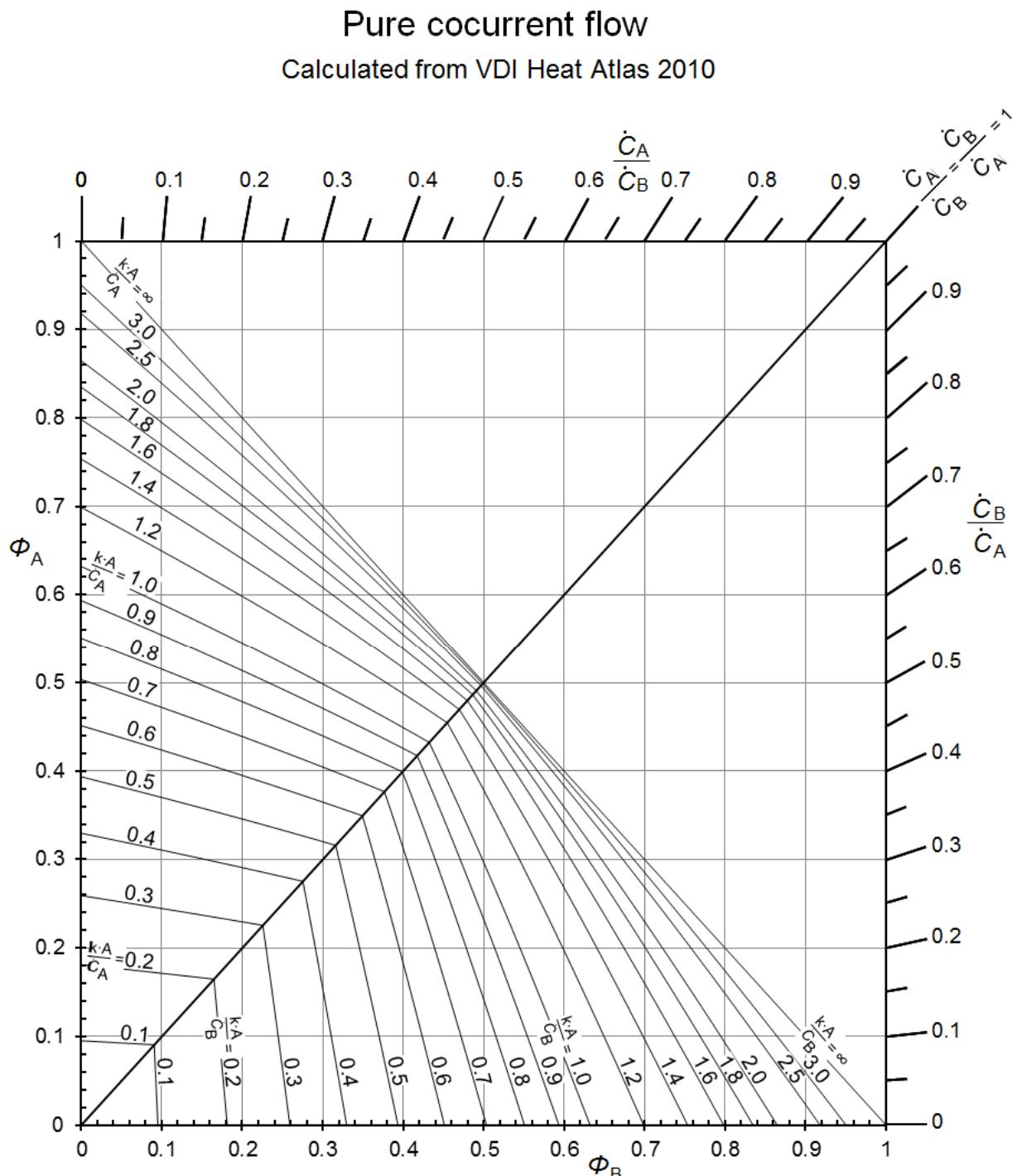
Pure counter current flow
Calculated from VDI Heat Atlas 2010



Prepared by Guido Keuchel

Zittau/Goerlitz University of Applied Sciences
Prof. Hans-Joachim Kretzschmar
Dr. Ines Stoecker
www.thermodynamik-zittau.de

Figure 5.1: Pure counter current flow - ITYPE 1



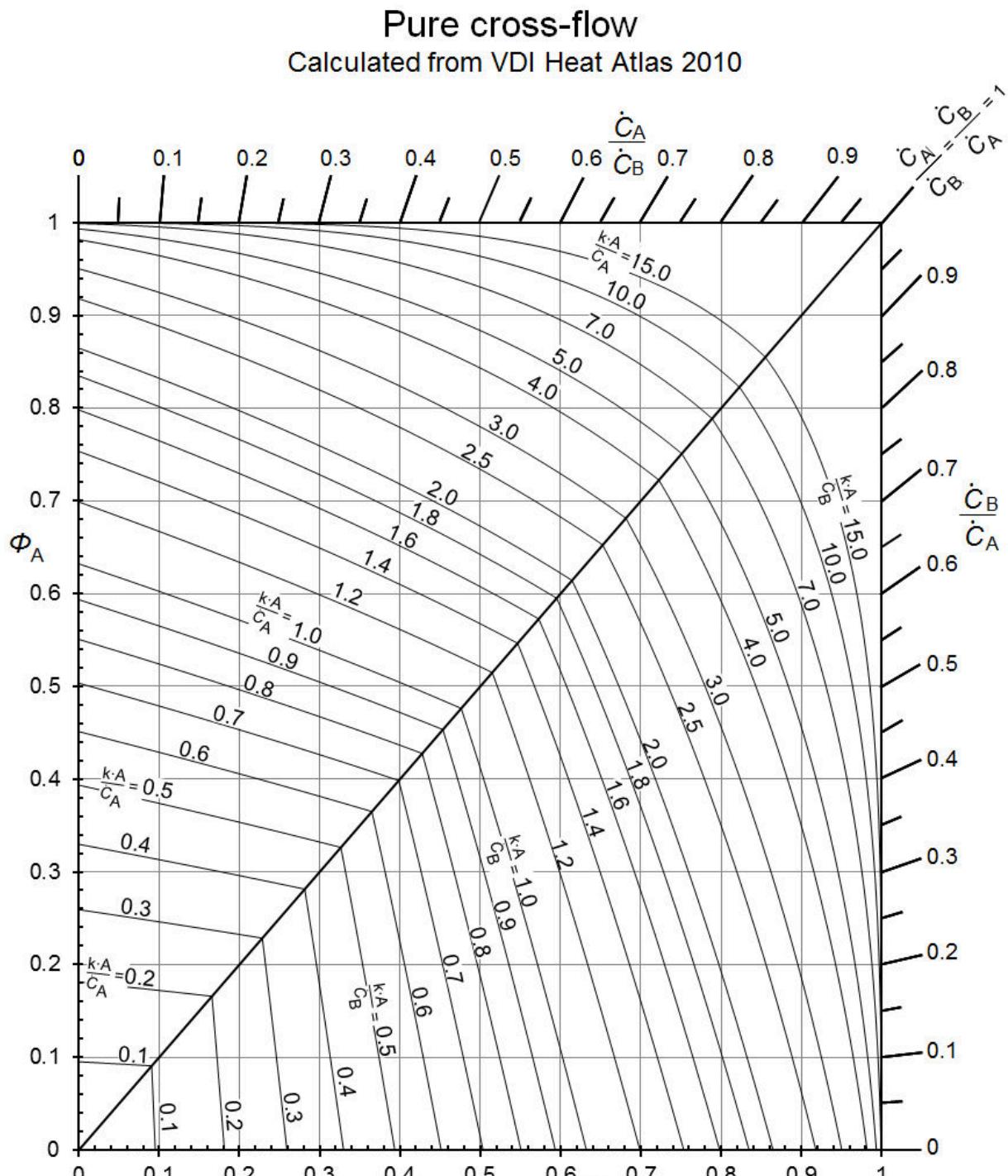
Prepared by Guido Keuchel

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Prof. Hans-Joachim Kretzschmar

Dr. Ines Stoecker

www.thermodynamik-zittau.de**Figure 5.2: Pure cocurrent flow - ITYPE 2**



Prepared by Guido Keuchel

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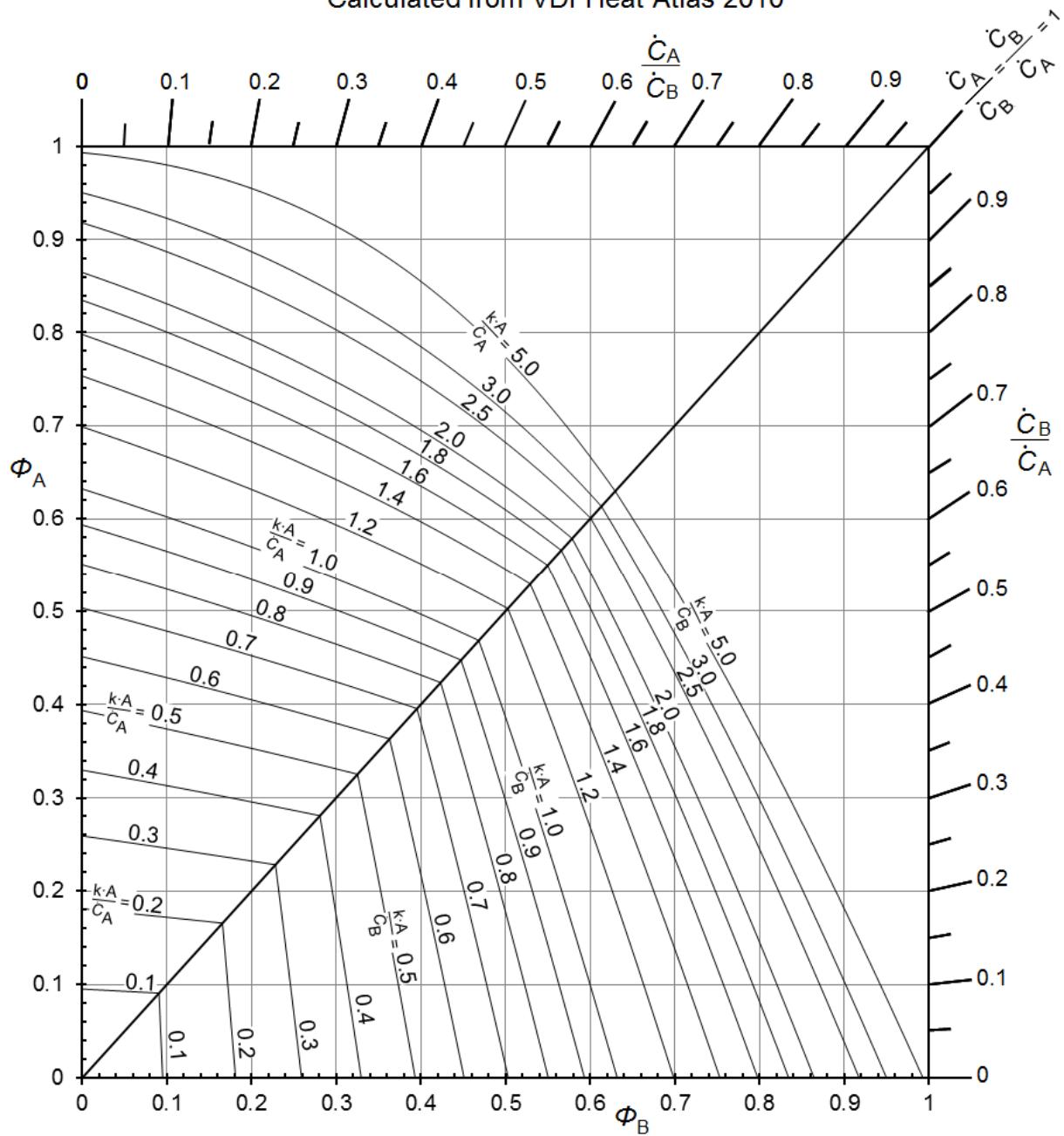
Prof. Hans-Joachim Kretzschmar

Dr. Ines Stoecker

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Figure 5.3: Pure cross-flow - ITYPE 3

**Cross-flow with one tube row,
laterally mixed on one side**
Calculated from VDI Heat Atlas 2010



Prepared by Guido Keuchel

Zittau/Goerlitz University of Applied Sciences

Prof. Hans-Joachim Kretzschmar

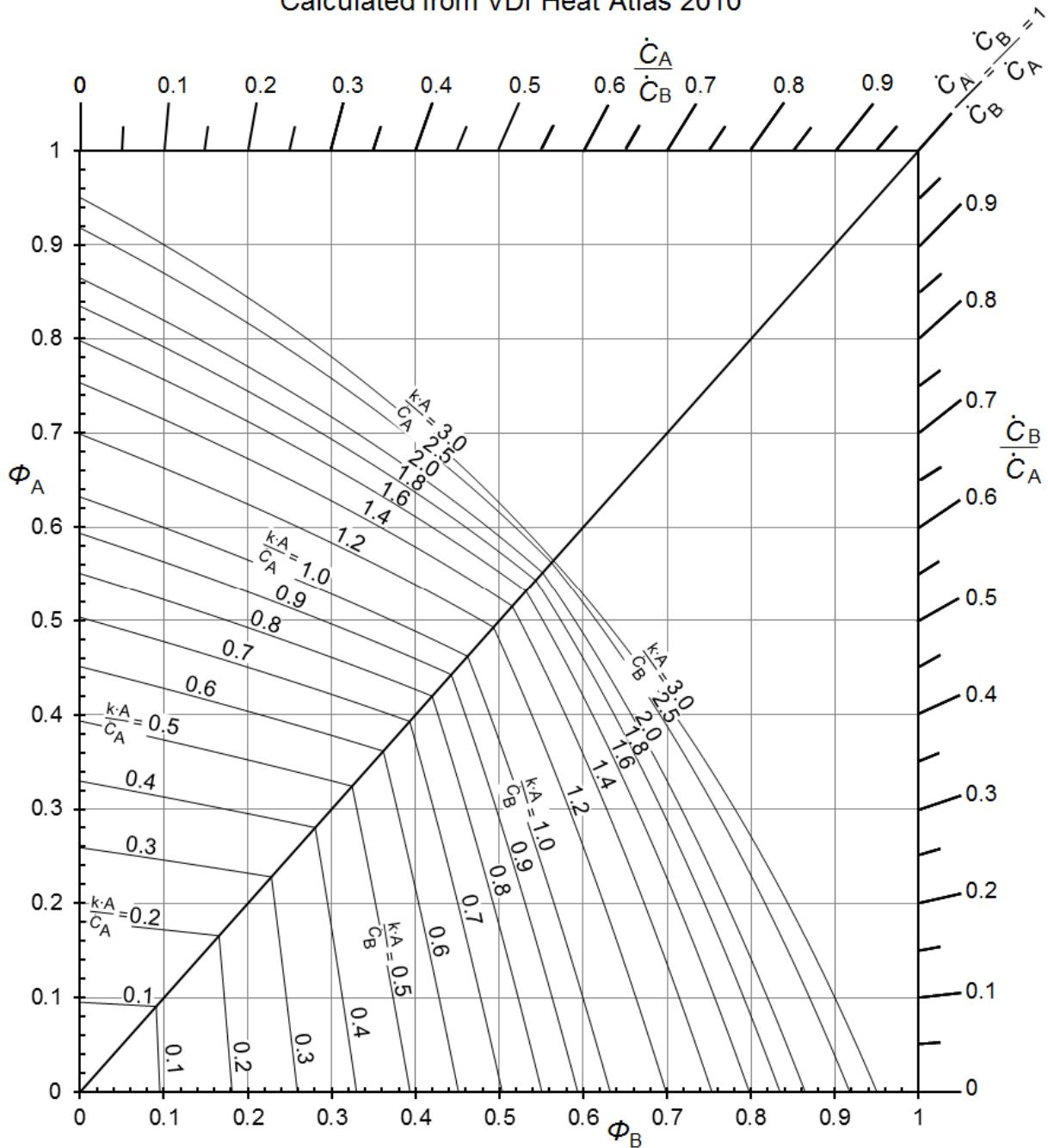
Dr. Ines Stoecker

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Figure 5.4: Cross-flow with one tube row, laterally mixed on one side - ITYPE 4

Cross-flow, laterally mixed on both sides

Calculated from VDI Heat Atlas 2010

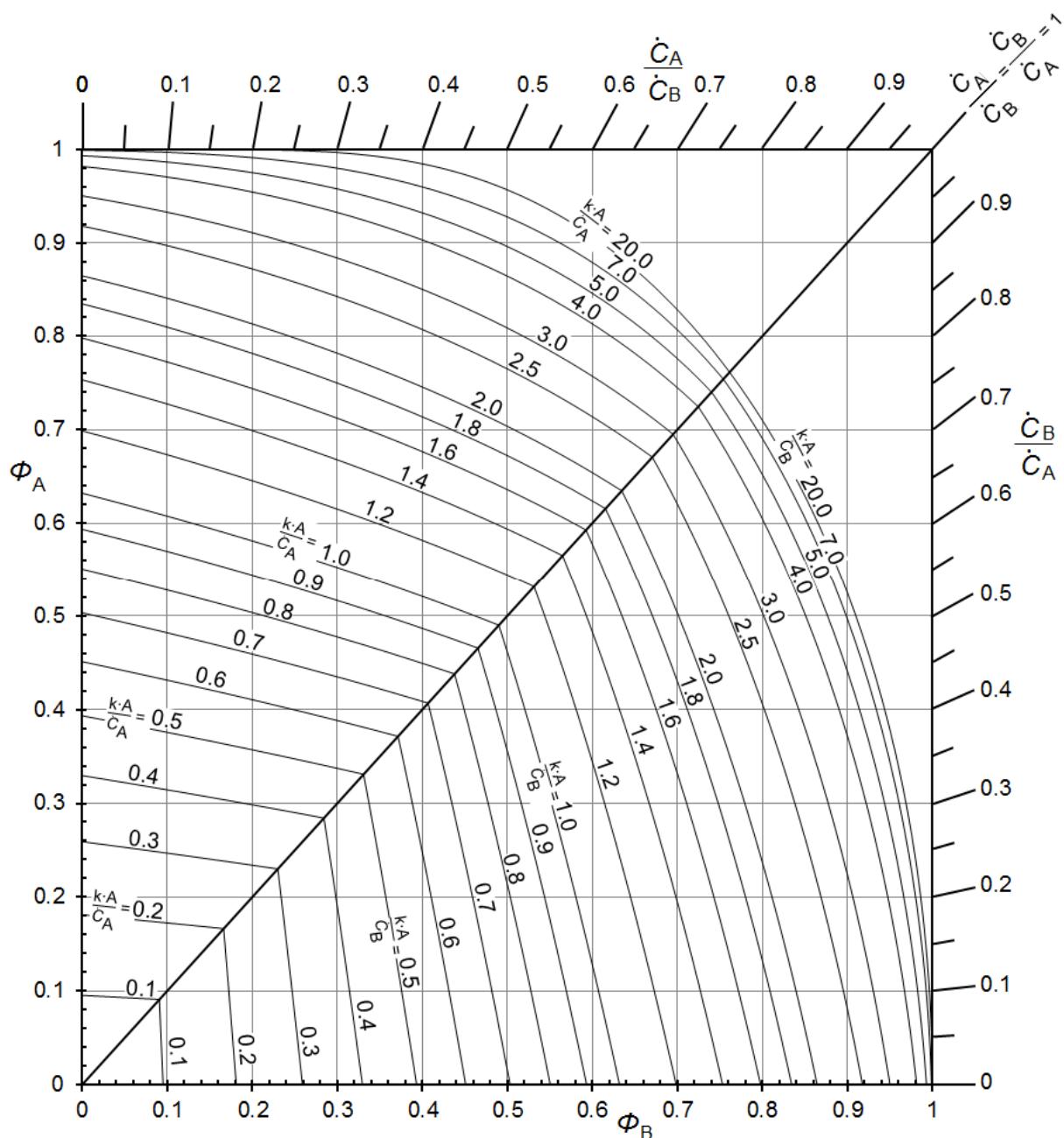


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Figure 5.5: Cross-flow, laterally mixed on both sides - ITYPE 5

**Counterdirected countercurrent cross-flow with
two tube rows and two passes**
Calculated from VDI Heat Atlas 2010



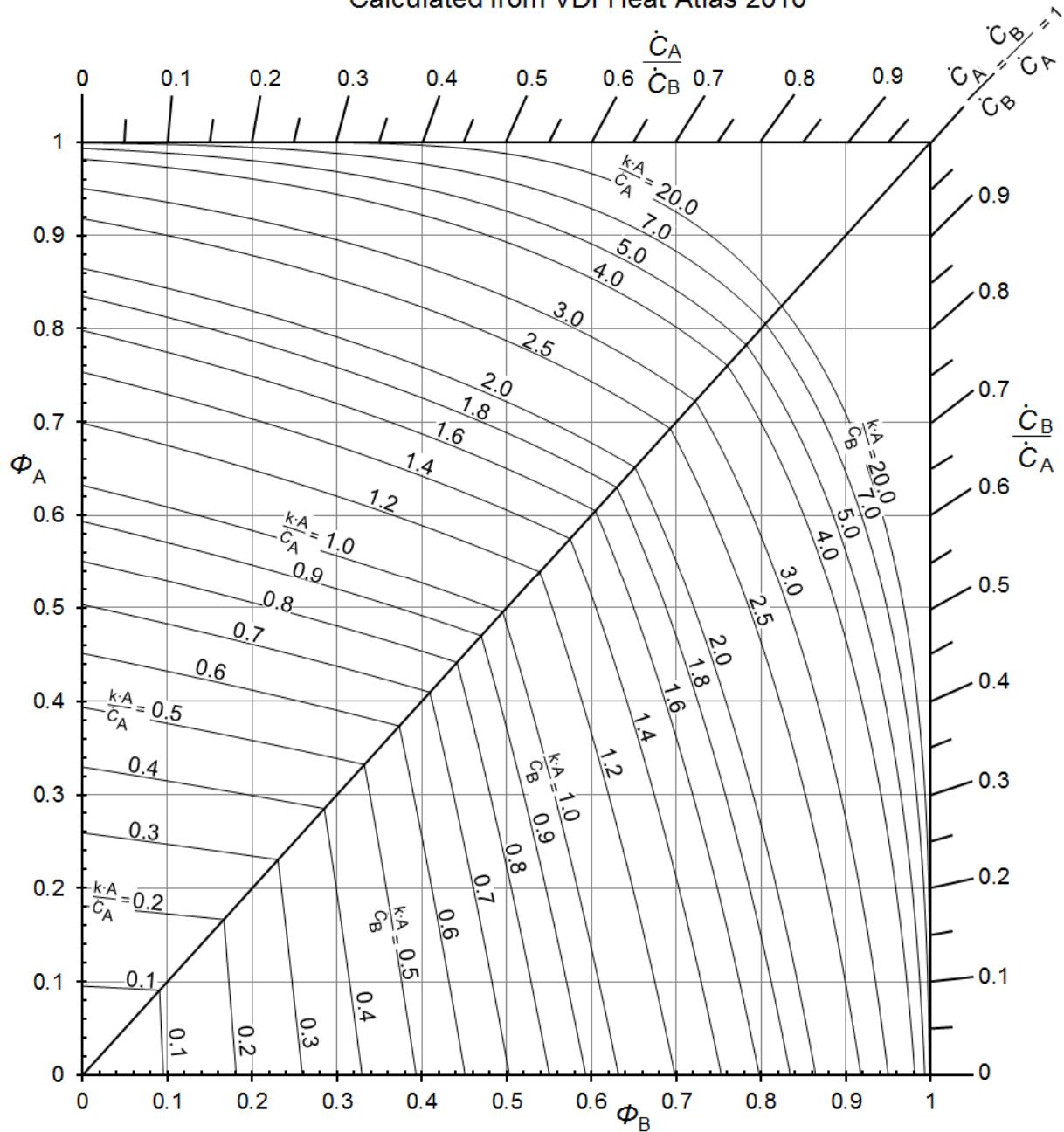
Prepared by Guido Keuchel

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Prof. Hans-Joachim Kretzschmar
Dr. Ines Stoecker
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Figure 5.6: Counterdirected countercurrent cross-flow with two tube rows and two passes - ITYPE 6

Counterdirected countercurrent cross-flow with three tube rows and three passes

Calculated from VDI Heat Atlas 2010

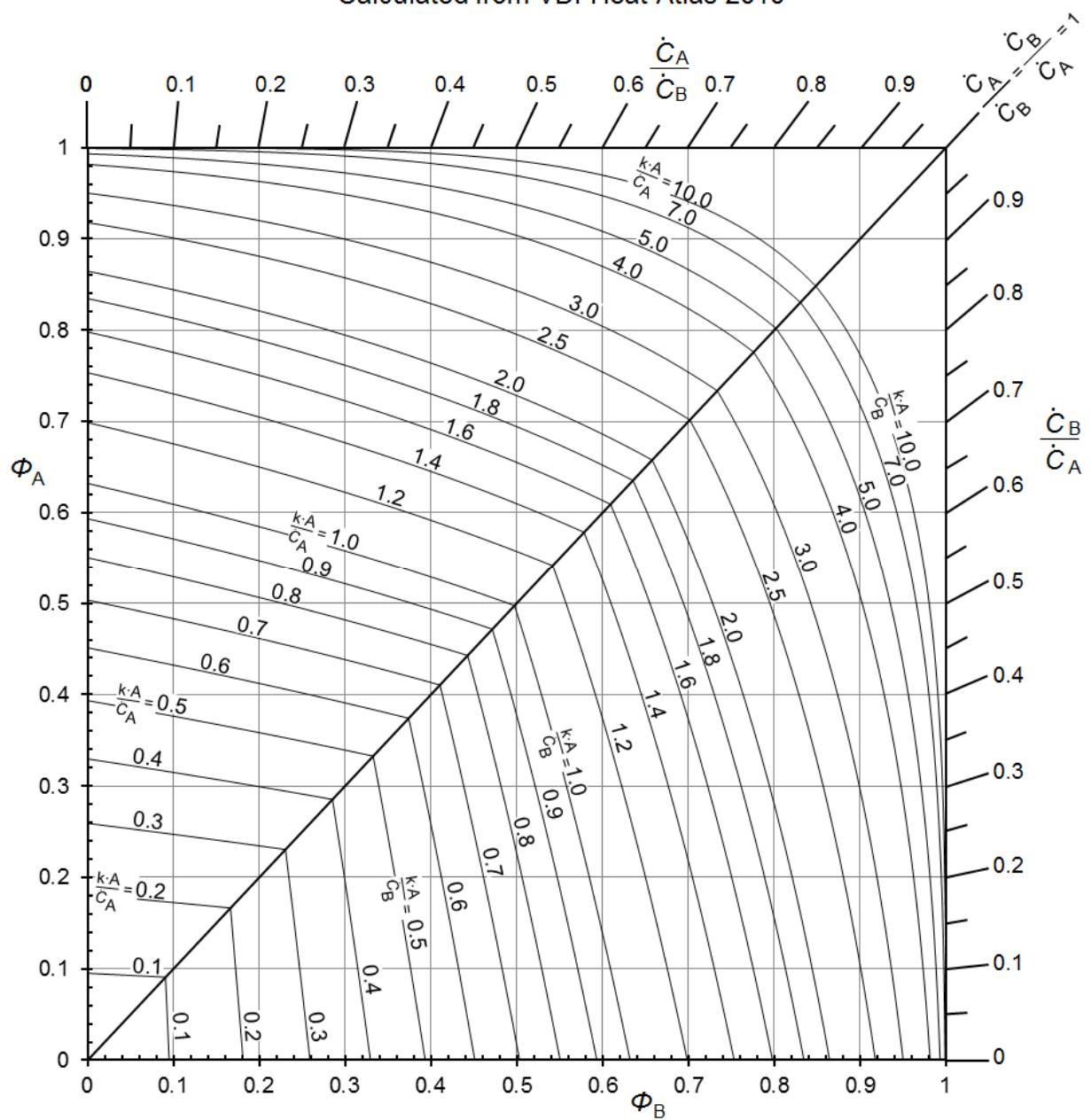


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 Prof. Hans-Joachim Kretzschmar
 Dr. Ines Stoecker
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Figure 5.7: Counterdirected countercurrent cross-flow with three tube rows and three passes - ITYPE 7

Counterdirected countercurrent cross-flow with
four tube rows and four passes
Calculated from VDI Heat Atlas 2010

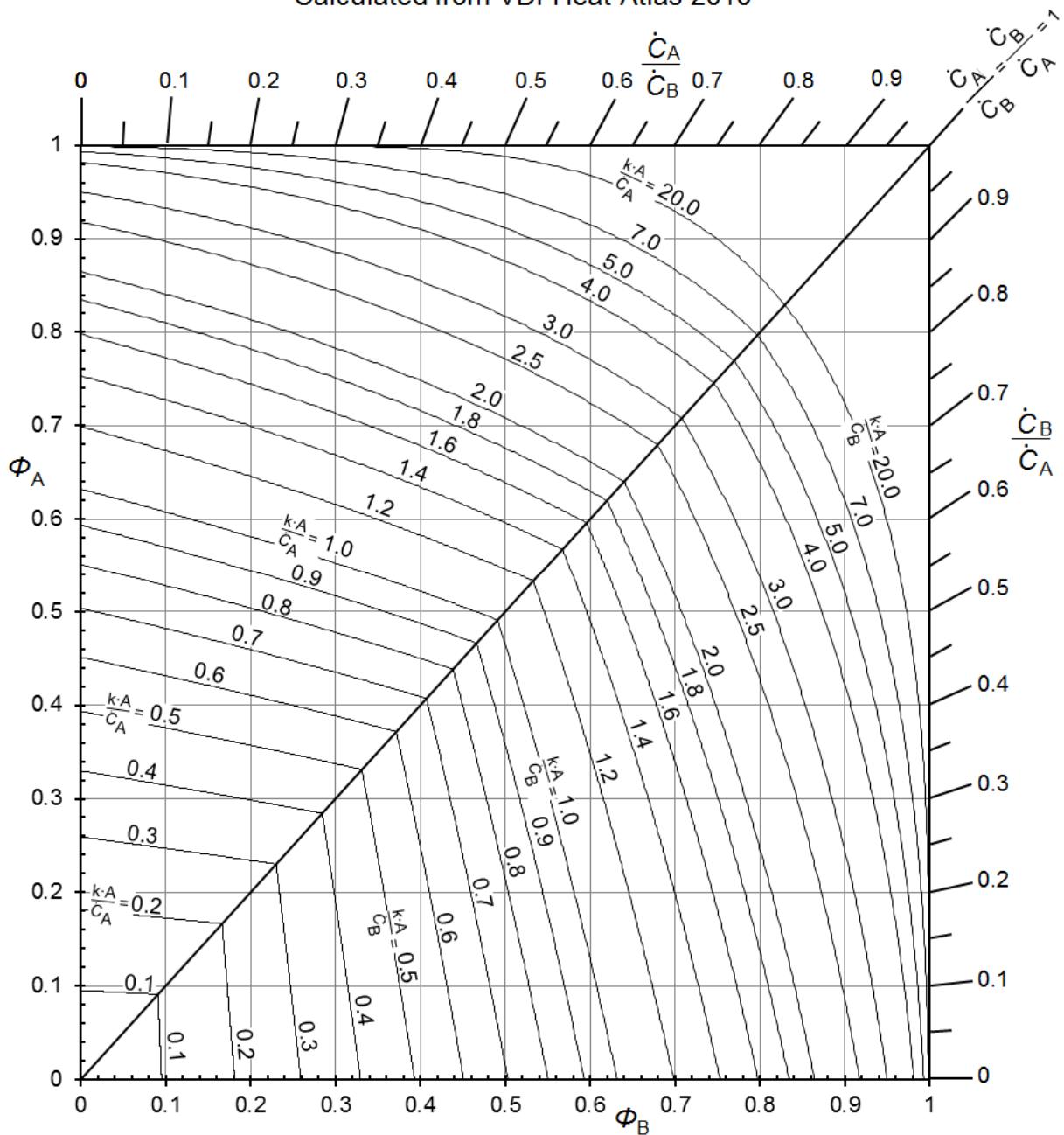


Prepared by Guido Keuchel

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Prof. Hans-Joachim Kretzschmar
Dr. Ines Stoecker
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Figure 5.8: Counterdirected countercurrent cross-flow with four tube rows and four passes - ITYPE 8

**Counterdirected countercurrent cross-flow
with four tube rows and two passes**
Calculated from VDI Heat Atlas 2010



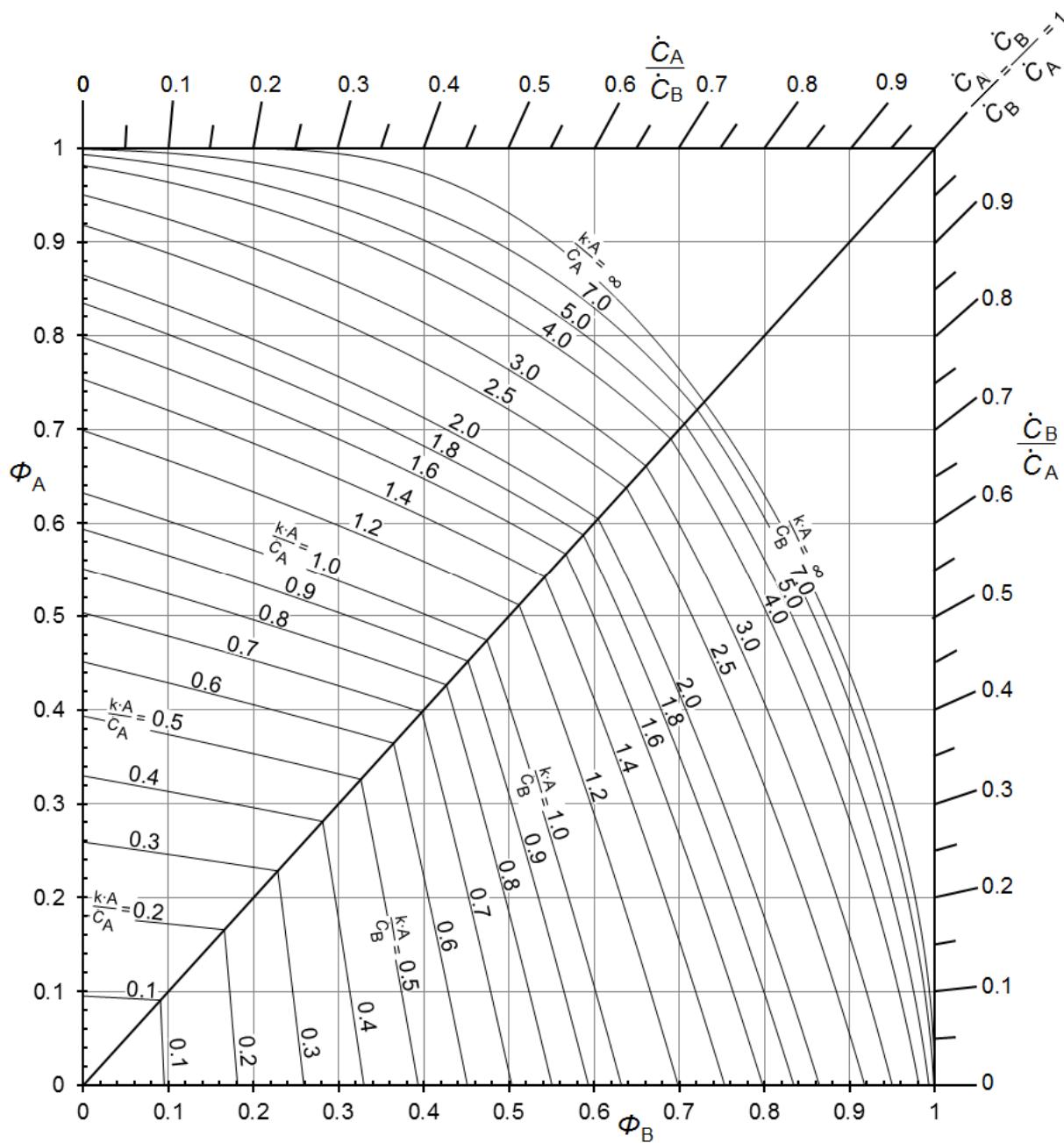
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Figure 5.9: Countercurrent-cross flow with four tube rows and two passes - ITYPE 9

Cross-flow with two tube rows and one pass

Calculated from VDI Heat Atlas 2010



Prepared by Guido Keuchel

Zittau/Goerlitz University of Applied Sciences

Prof. Hans-Joachim Kretzschmar

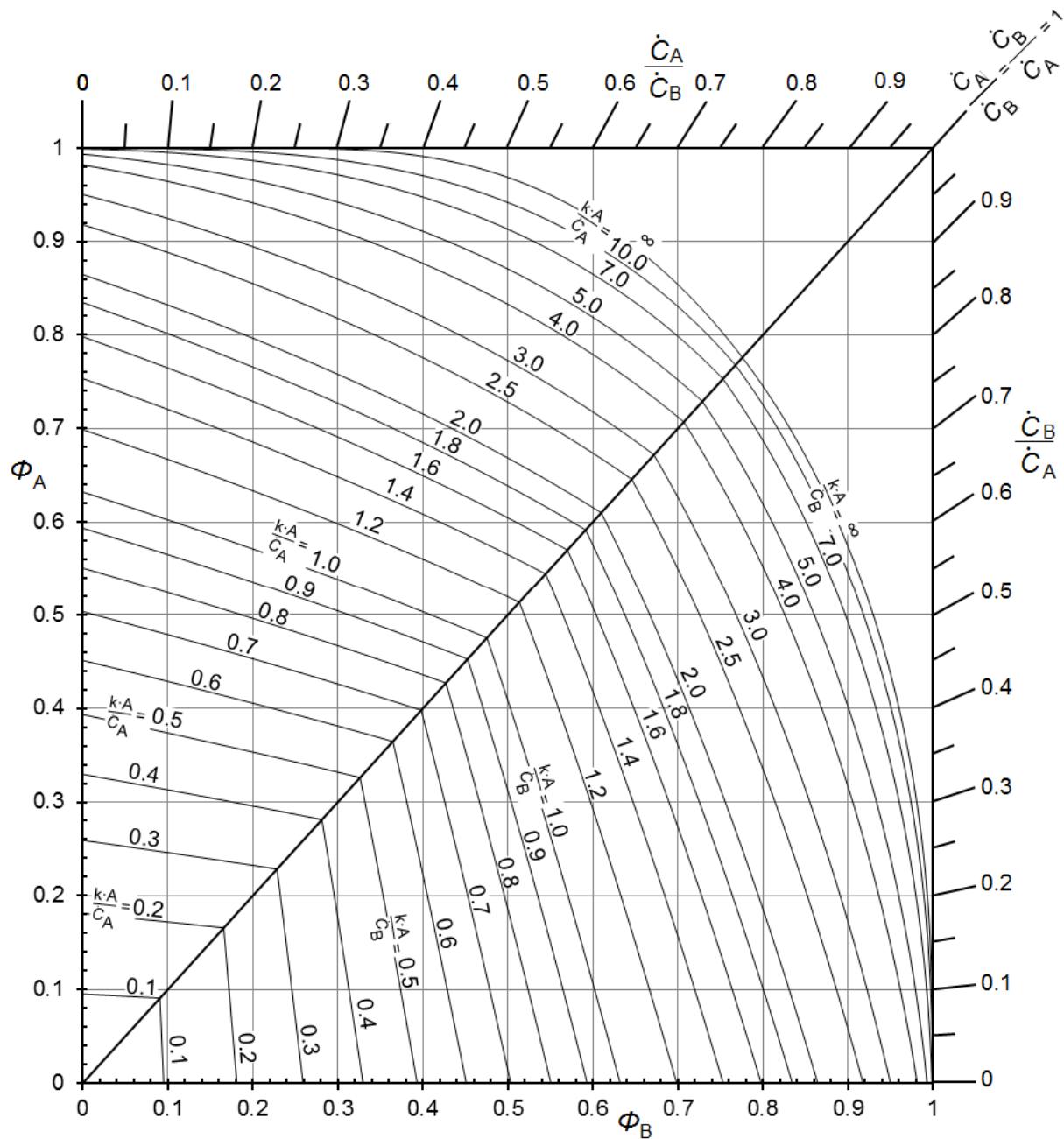
Dr. Ines Stoecker

www.thermodynamik-zittau.de

Figure 5.10: Cross-flow with two tube rows and one pass - ITYPE 10 and NSPEC 2

Cross-flow with three tube rows and one pass

Calculated from VDI Heat Atlas 2010



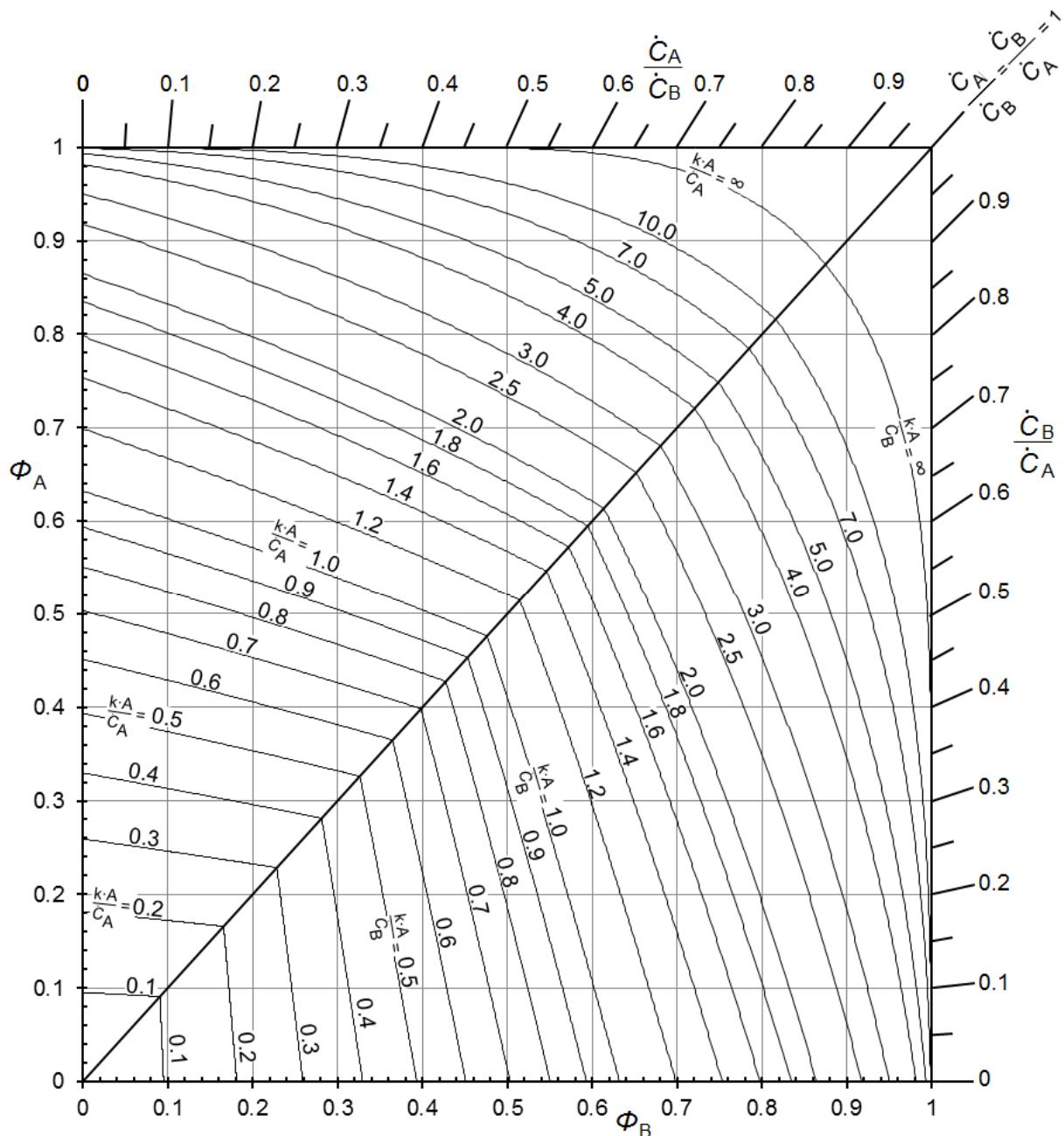
Prepared by Guido Keuchel

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Dr. Ines Stoecker
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Figure 5.11: Cross-flow with three tube rows and one pass - ITYPE 10 and NSPEC 3

Cross-flow with ten tube rows and one pass

Calculated from VDI Heat Atlas 2010



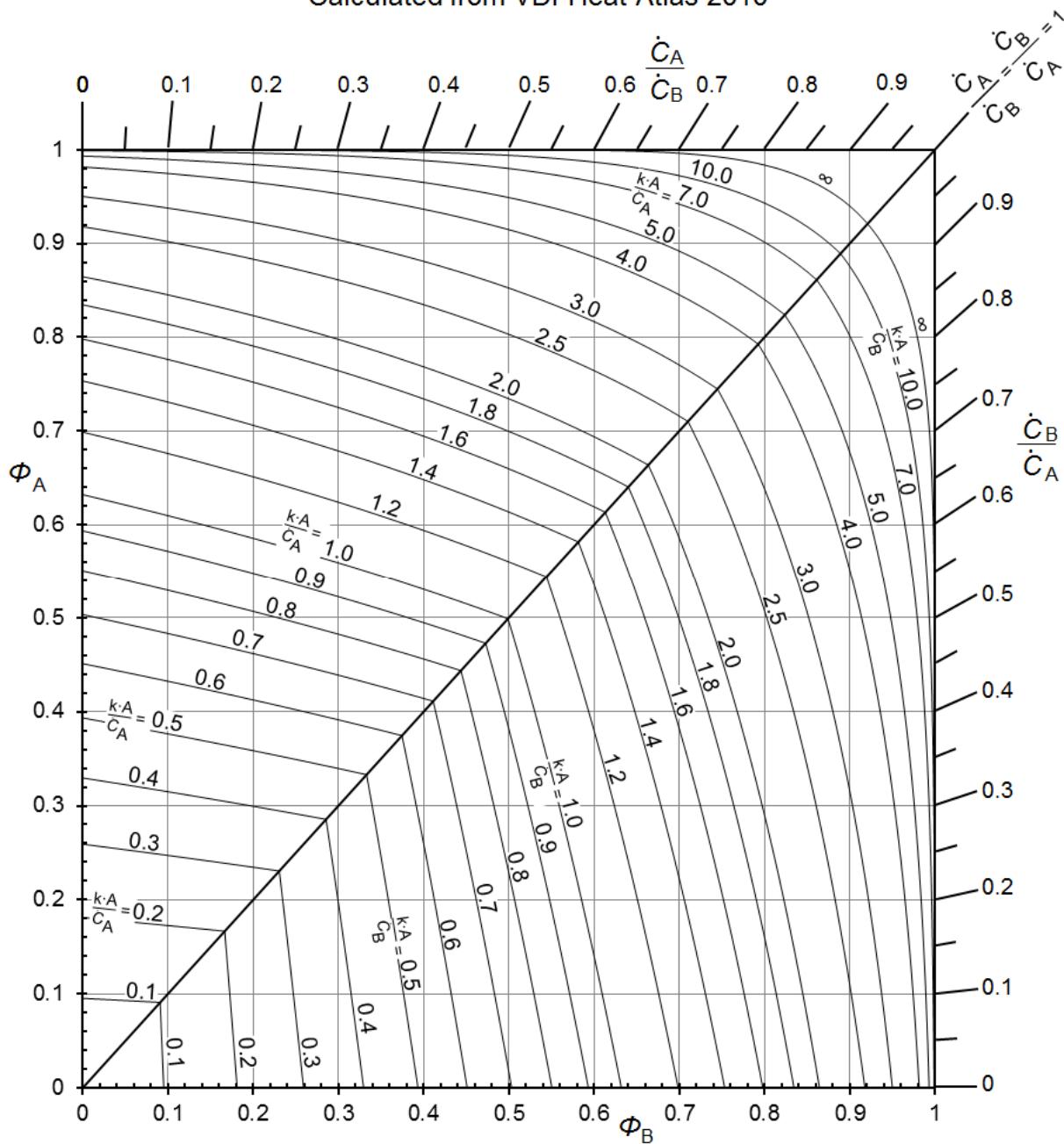
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Figure 5.12: Cross-flow with ten tube rows and one pass - ITYPE 10 and NSPEC 10

Codirected countercurrent cross-flow with six tube rows and six passes

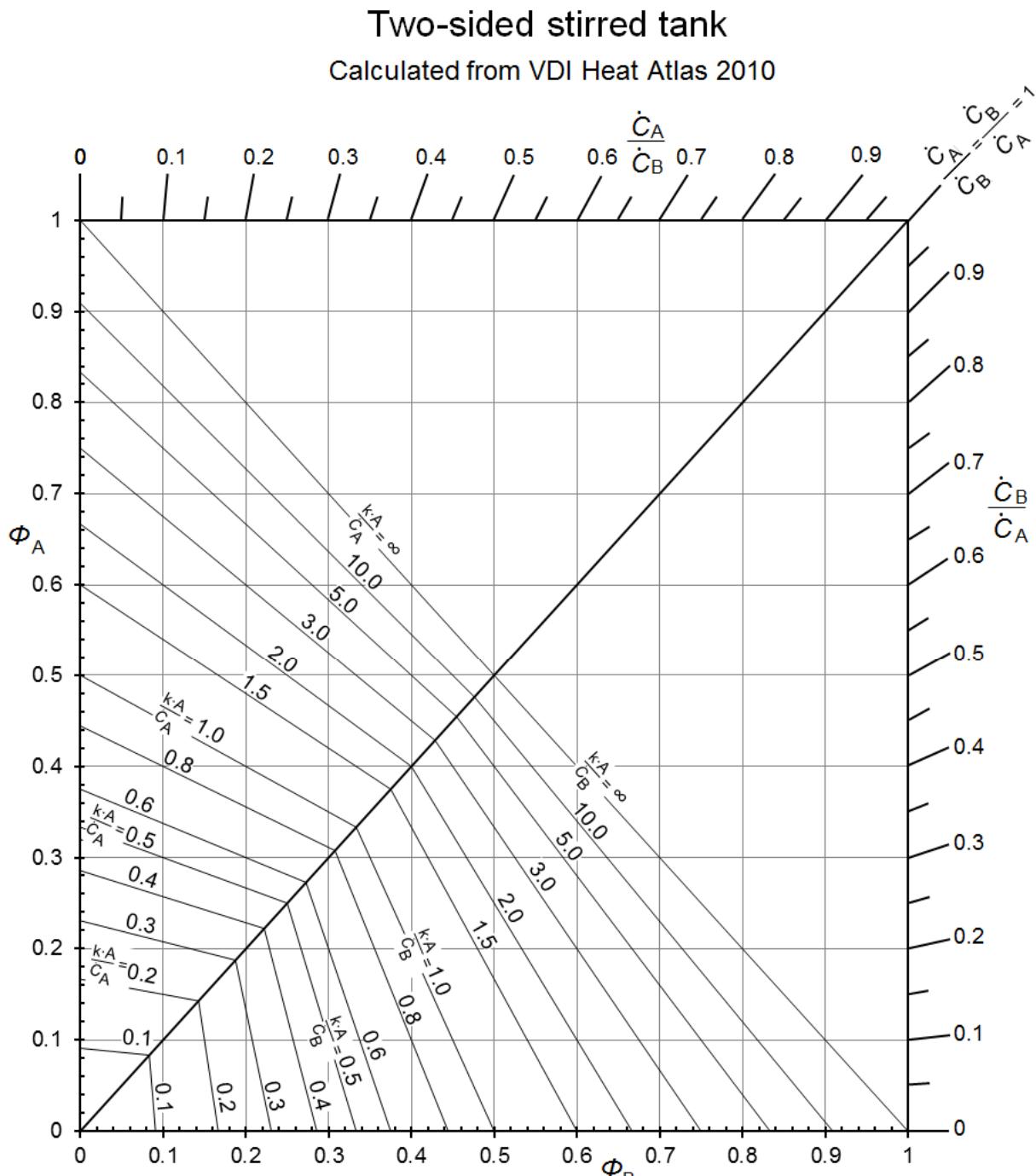
Calculated from VDI Heat Atlas 2010



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**Figure 5.13: Codirected countercurrent cross-flow with six tube rows and
six passes - ITYPE 11 and NSPEC 6**



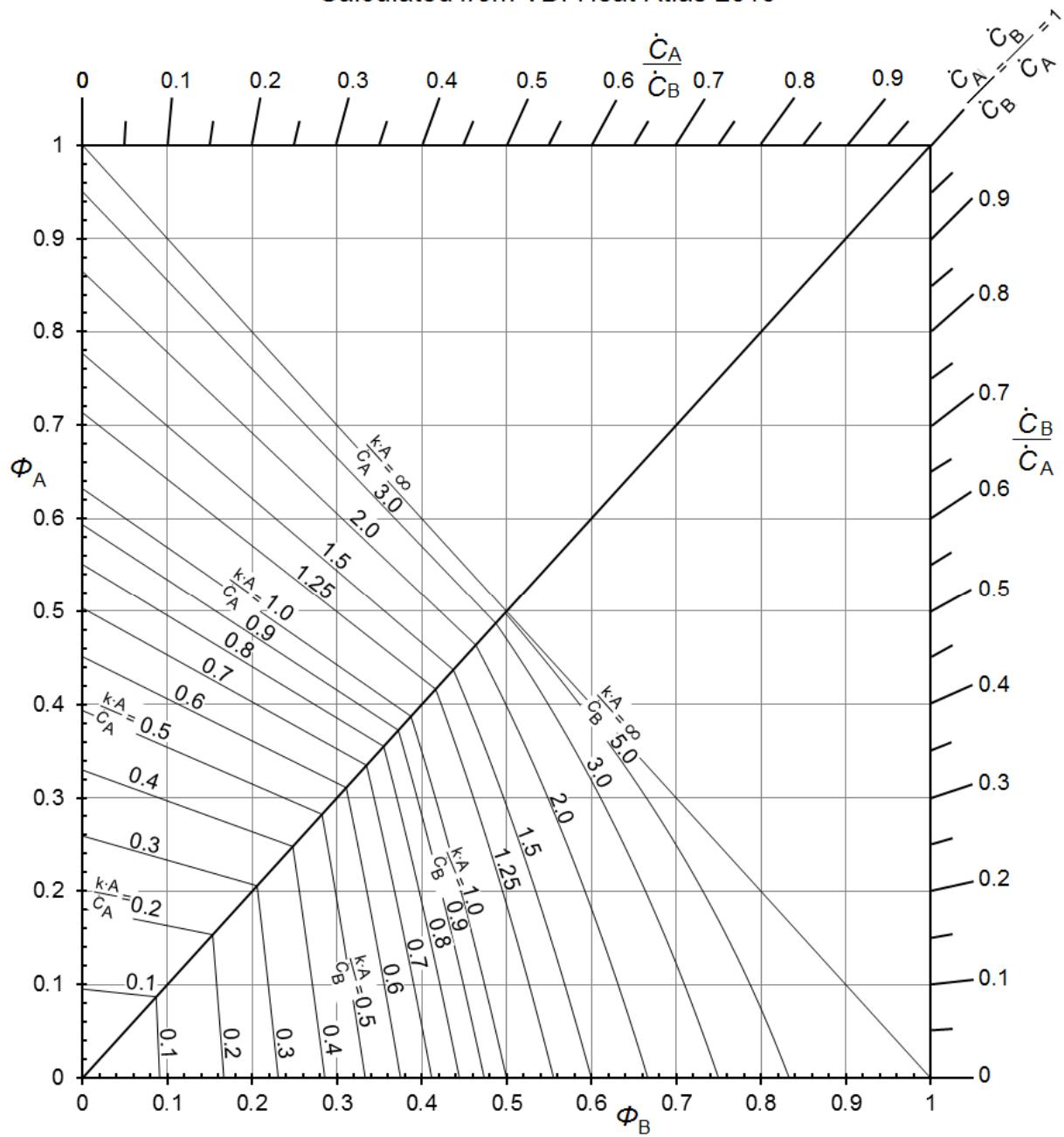
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Figure 5.14: Two-sided stirred tank - ITYPE 12

One-sided stirred tank

Calculated from VDI Heat Atlas 2010



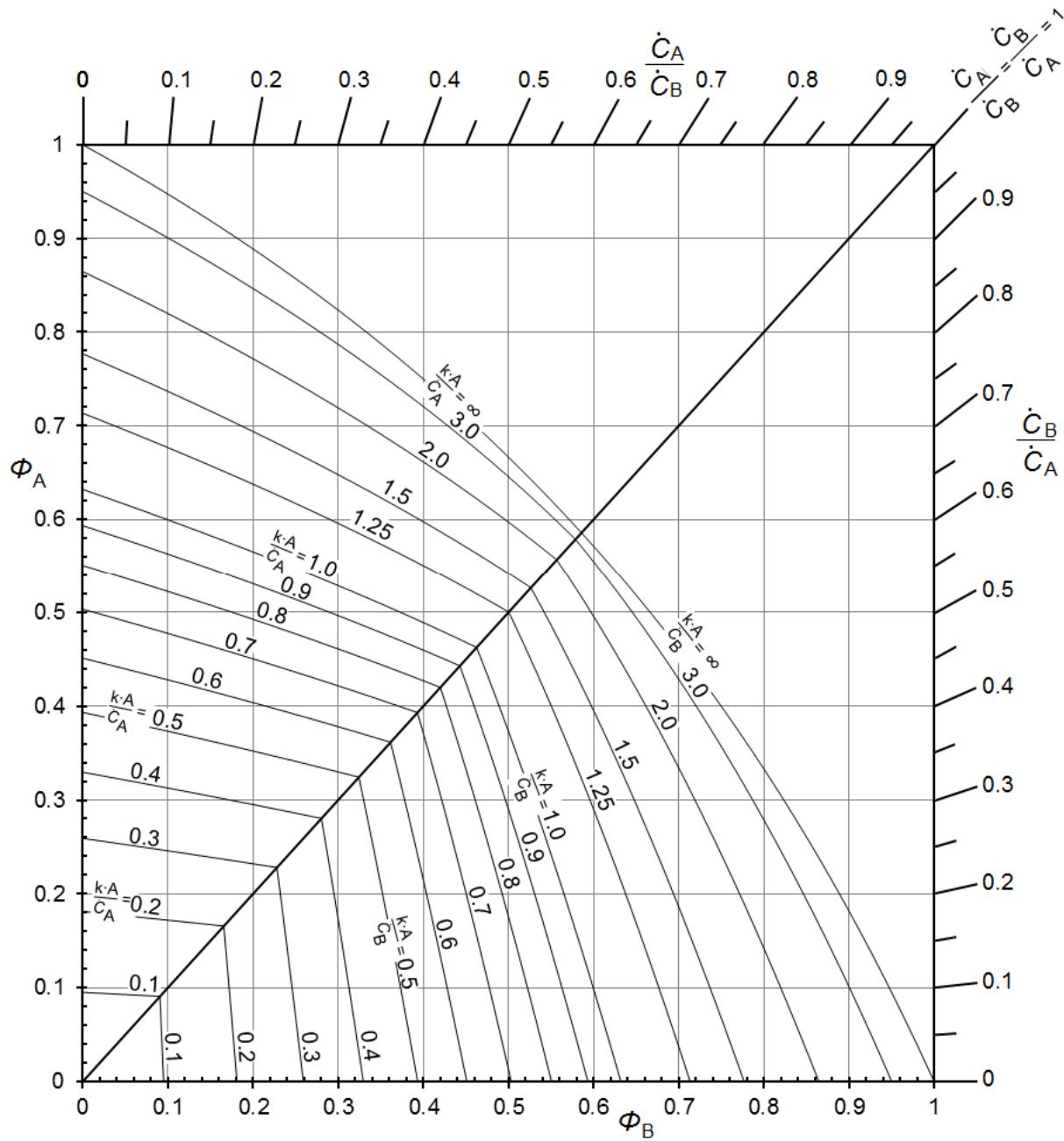
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Figure 5.15: One-sided stirred tank - ITYPE 13

One shell-side and two tube-side passes

Calculated from VDI Heat Atlas 2010

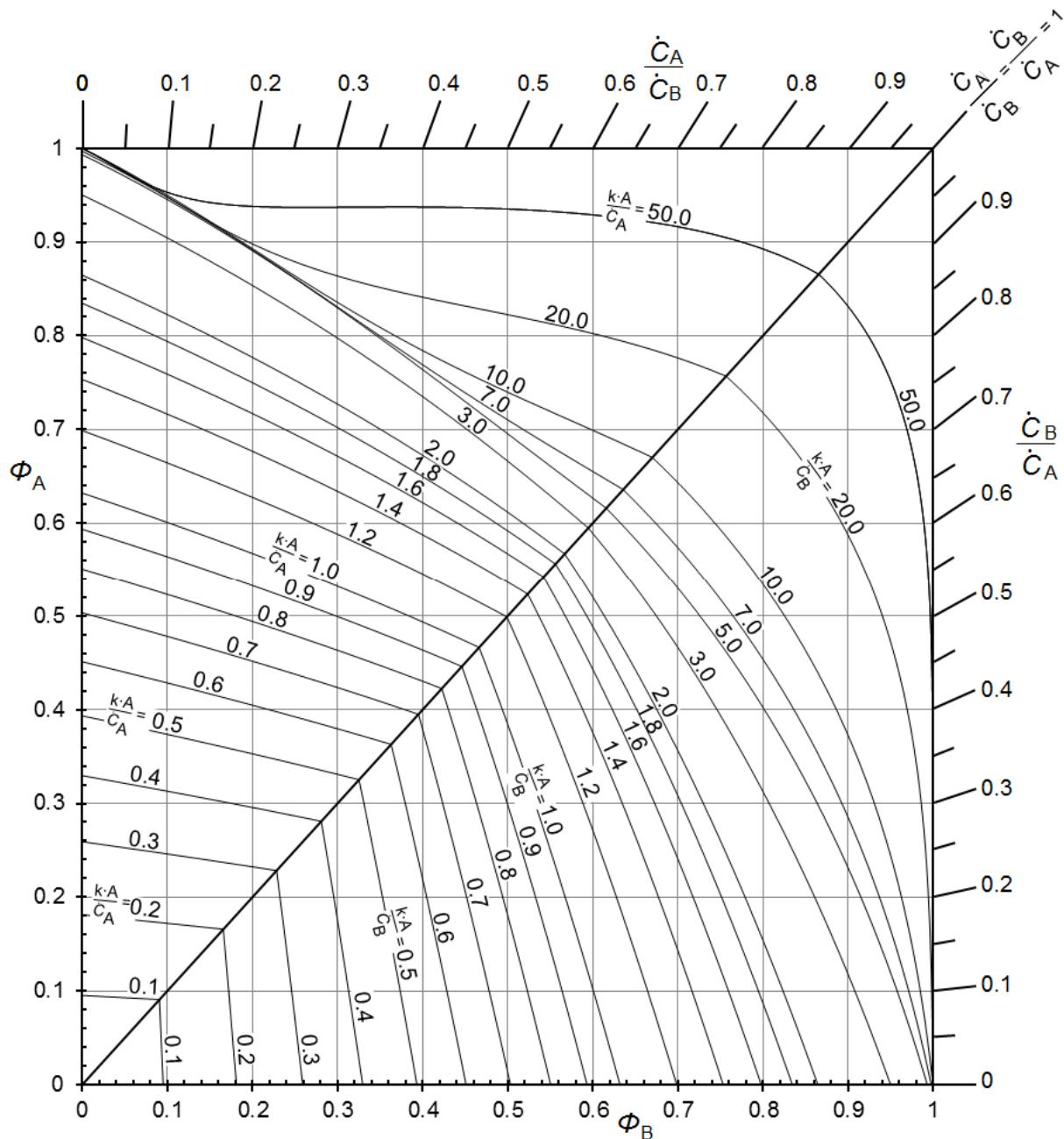


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Figure 5.16: One shell-side and two tube-side passes - ITYPE 14

One shell-side and three tubeside passes,
two countercurrent
Calculated from VDI Heat Atlas 2010

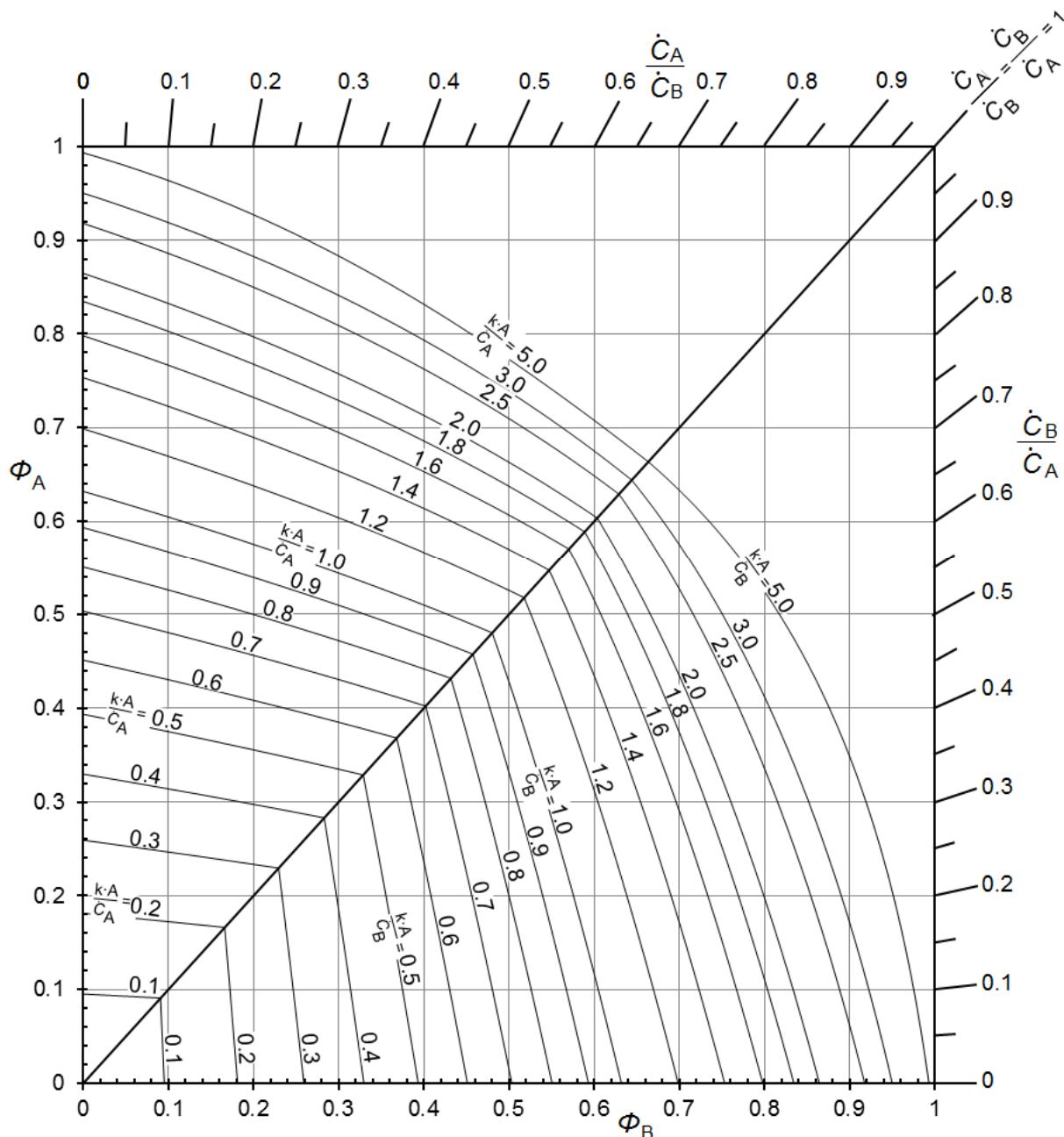


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Figure 5.17: One shell-side and three tube-side passes, two countercurrent - ITYPE 15

**One shell-side and two tubeside passes,
both countercurrent**
Calculated from VDI Heat Atlas 2010



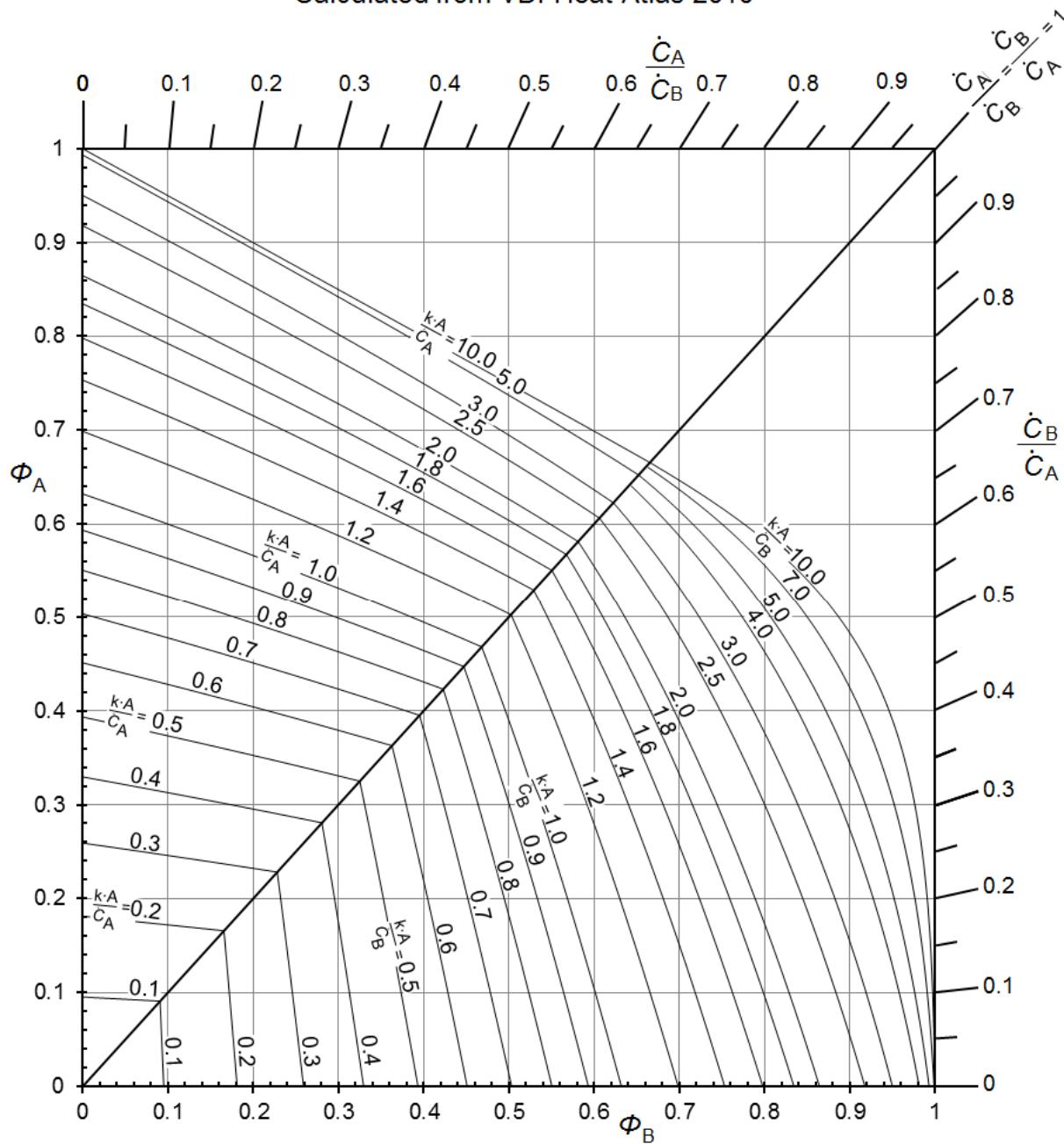
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Figure 5.18: One shell-side and two tube-side passes, both countercurrent - ITYPE 16

Divided flow with one shellside and one tube-side pass

Calculated from VDI Heat Atlas 2010

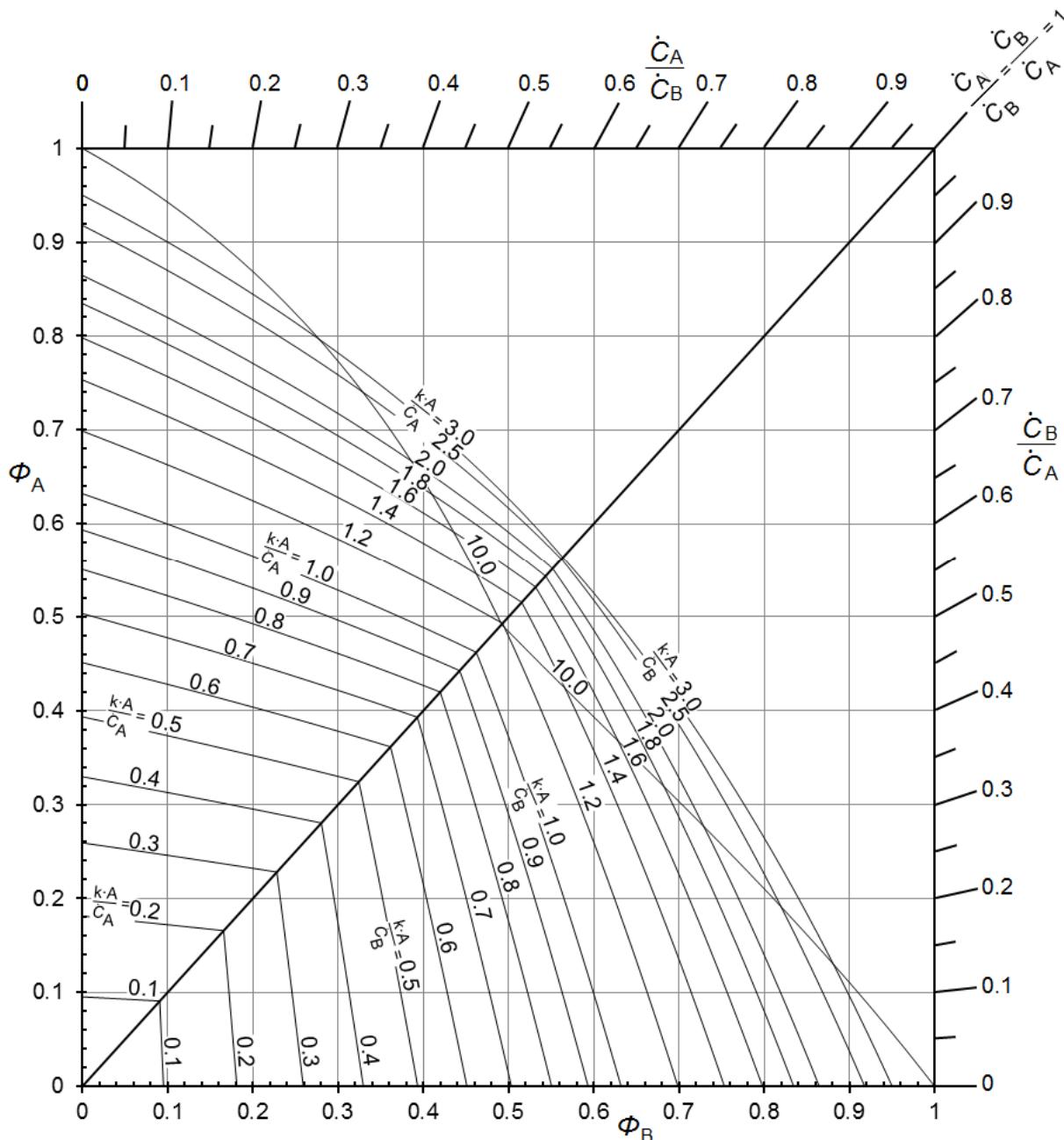


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Figure 5.19: Divided flow with one shellside and one tube-side pass - ITYPE 17

**Divided flow with one shell-side and
two tube-side passes**
Calculated from VDI Heat Atlas 2010



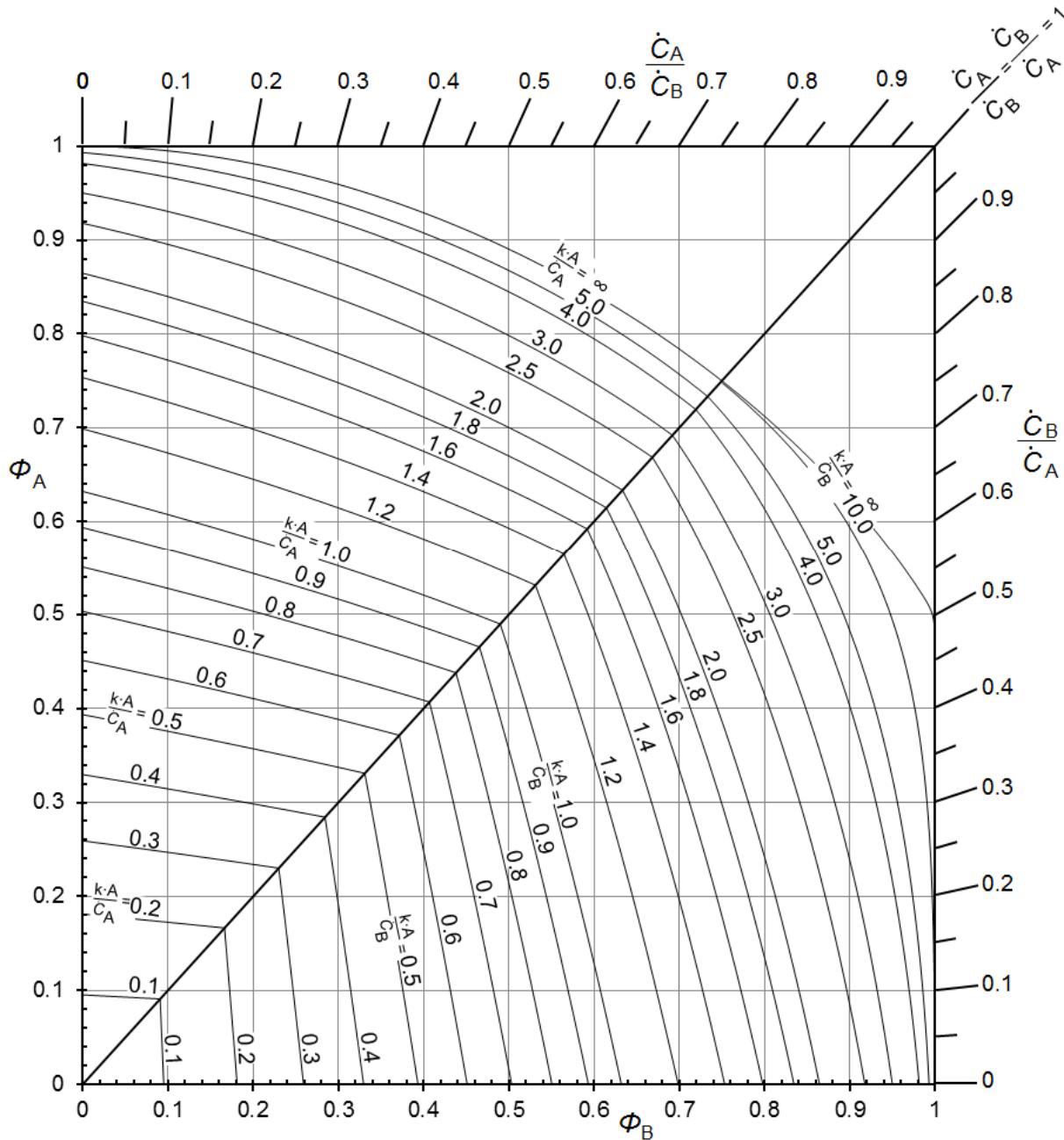
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Figure 5.20: Divided flow with one shell-side and two tube-side passes - ITYPE 18

Split flow with longitudinal baffle and two shell-side and two tube-side passes (tube-side outlet and shellside inlet at the same side)

Calculated from VDI Heat Atlas 2010



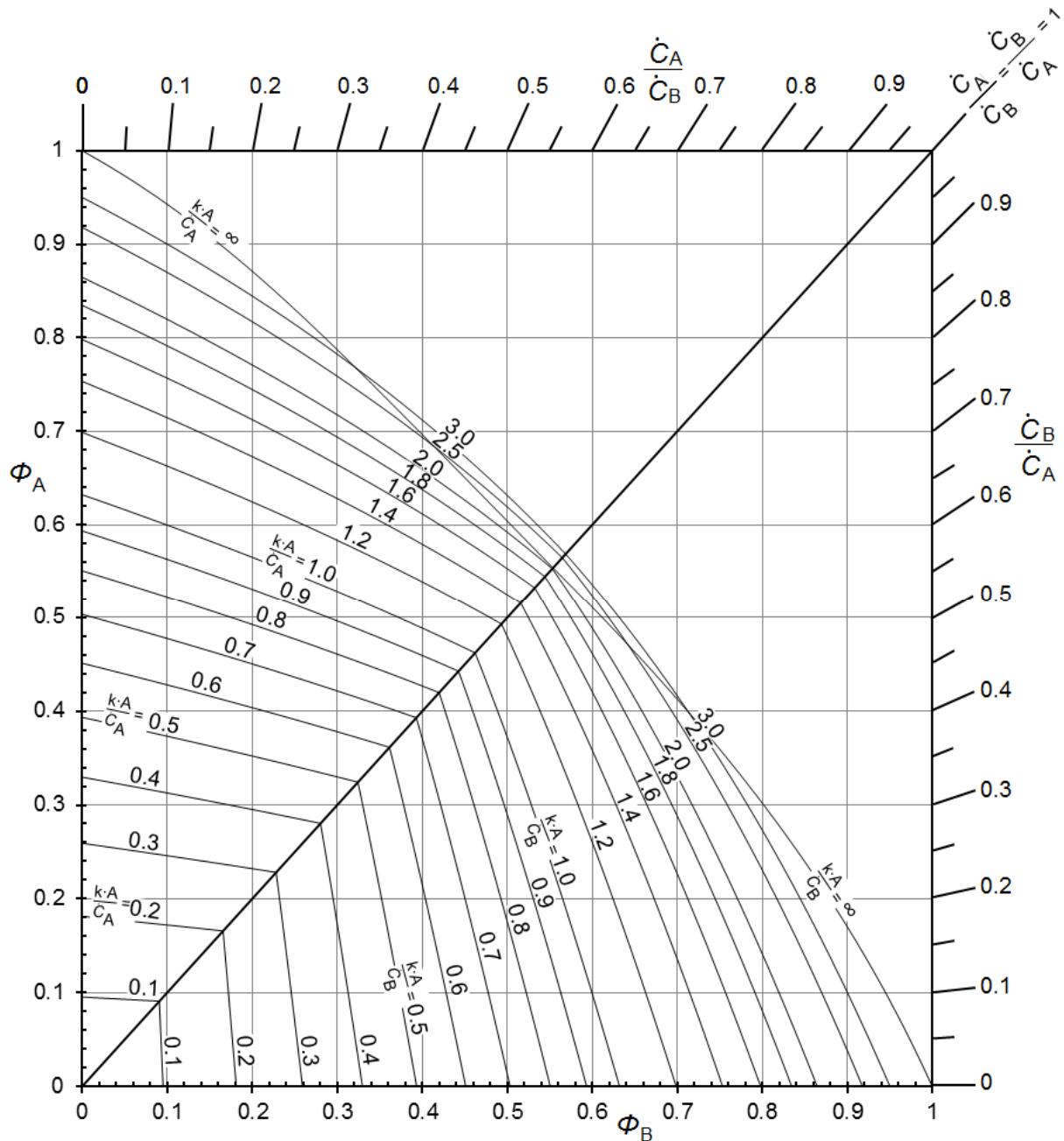
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Figure 5.21: Split flow with longitudinal baffle and two shell-side and two tube-side passes (tube-side outlet and shell-side inlet on the same side) - ITYPE 19

One shell-side and four tube-side passes

Calculated from VDI Heat Atlas 2010

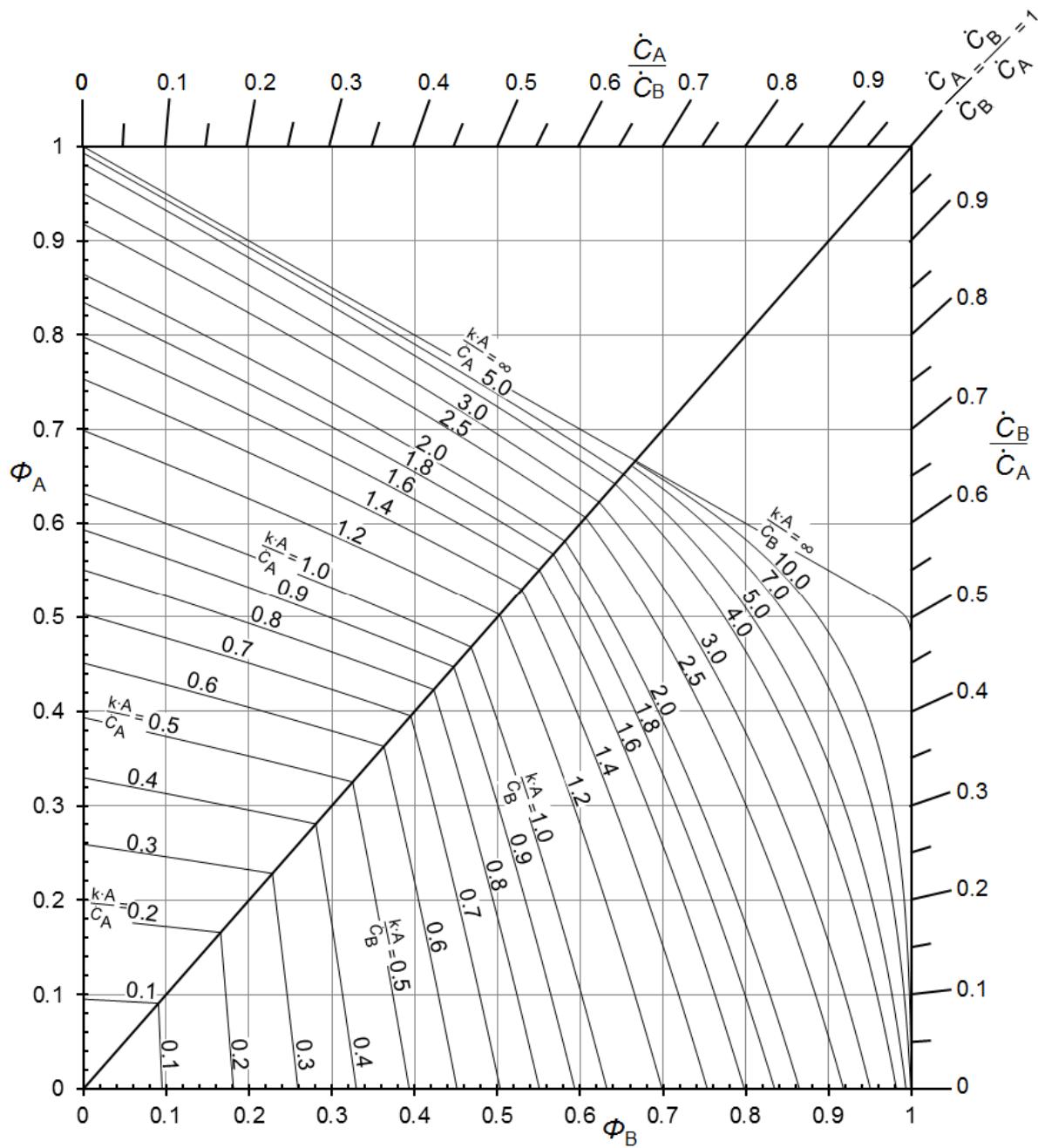


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Figure 5.22: One shell-side and four tube-side passes - ITYPE 20 and NSPEC 2

One pass for stream 1 and two passes for stream 2
 Calculated from VDI Heat Atlas 2010

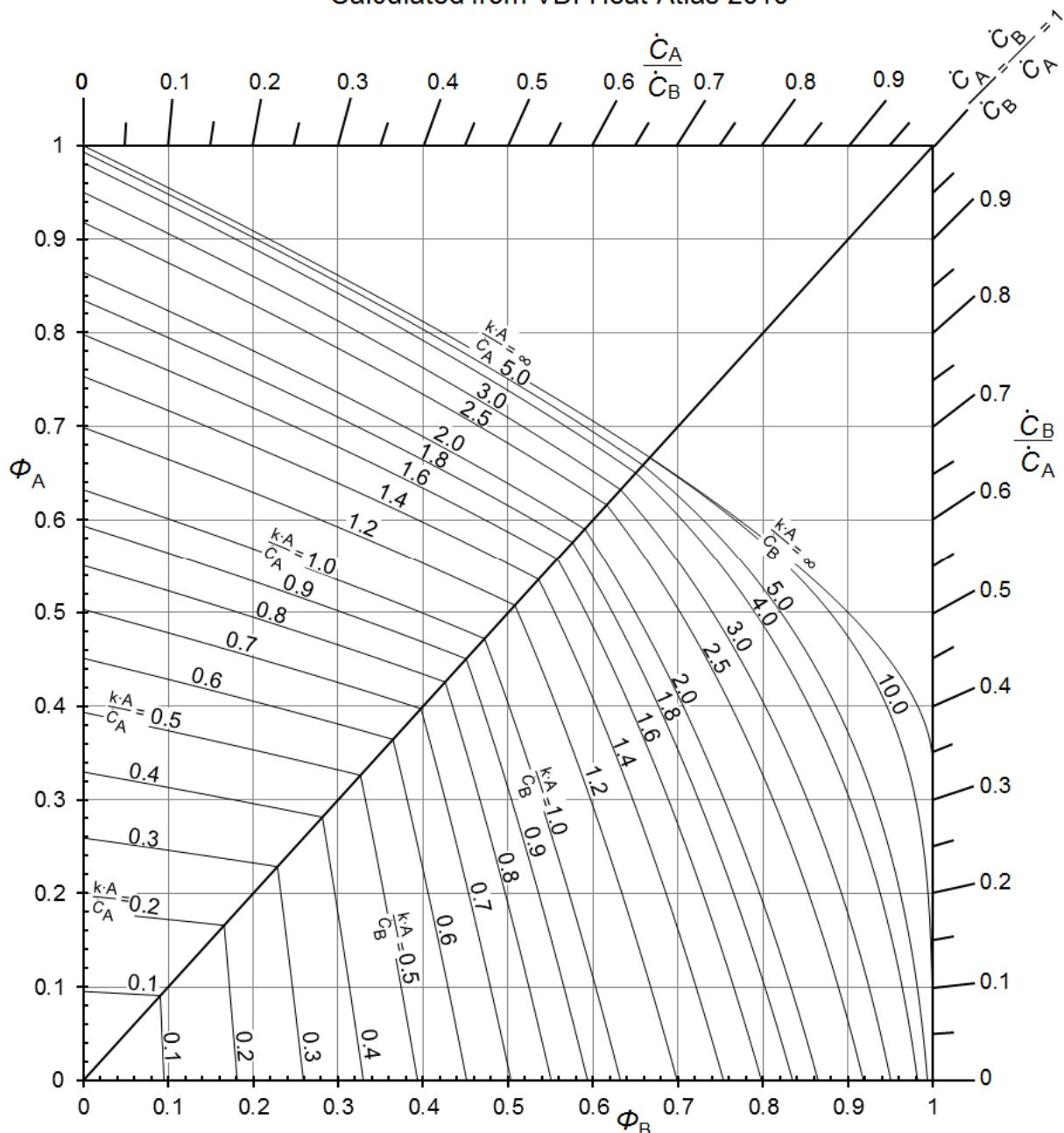


Prepared by Guido Keuchel
 Bearbeitet von Dipl.-Ing. (FH) G. Keuchel

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Figure 5.23: One pass for stream 1 and two passes for stream 2 - ITYPE 21

One pass for stream 1 and three passes for stream 2,
two in countercurrent
Calculated from VDI Heat Atlas 2010

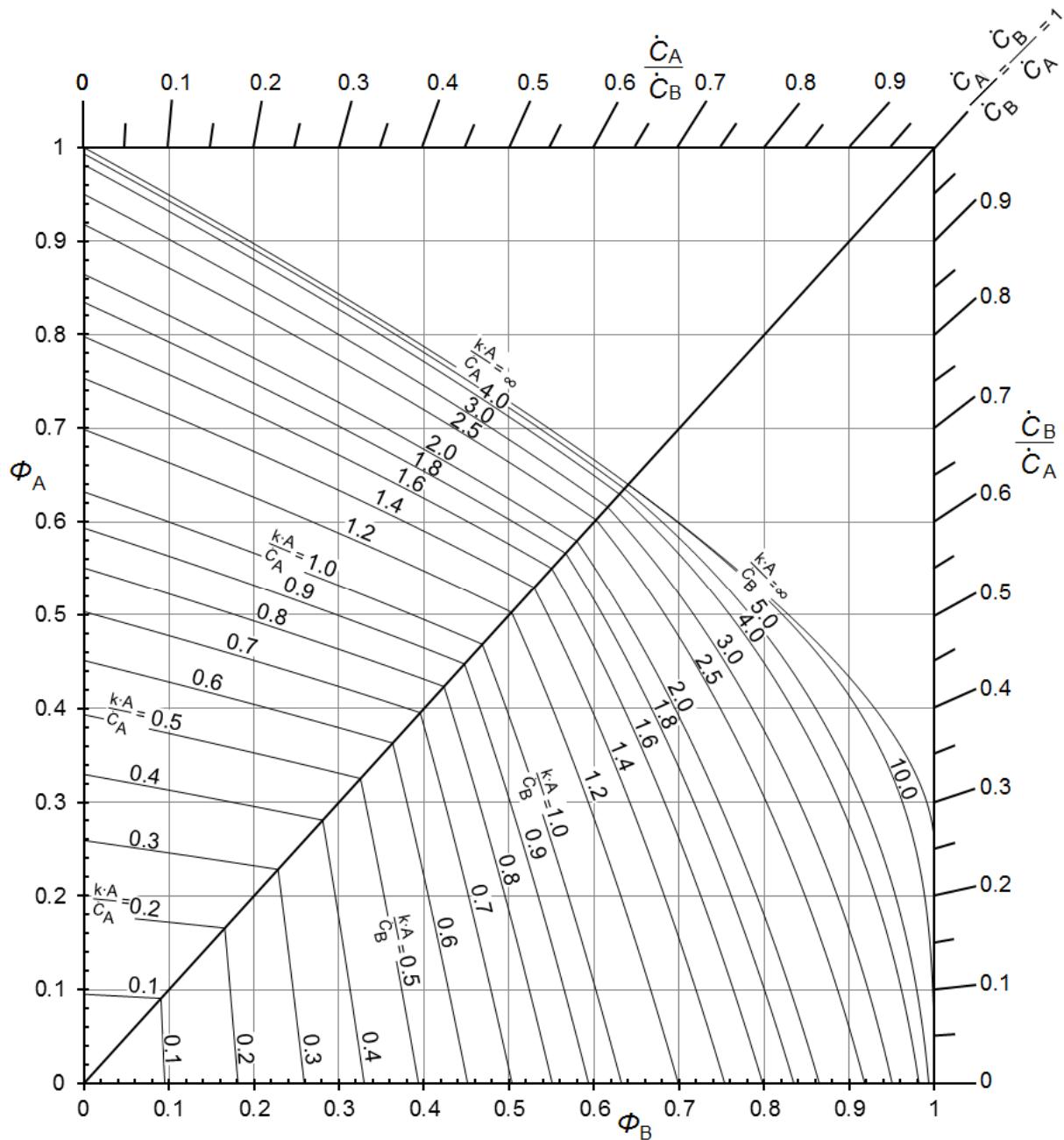


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**Figure 5.24: One pass for stream 1 and three passes for stream 2,
two in countercurrent - ITYPE 22**

One pass for stream 1 and four passes for stream 2
 Calculated from VDI Heat Atlas 2010

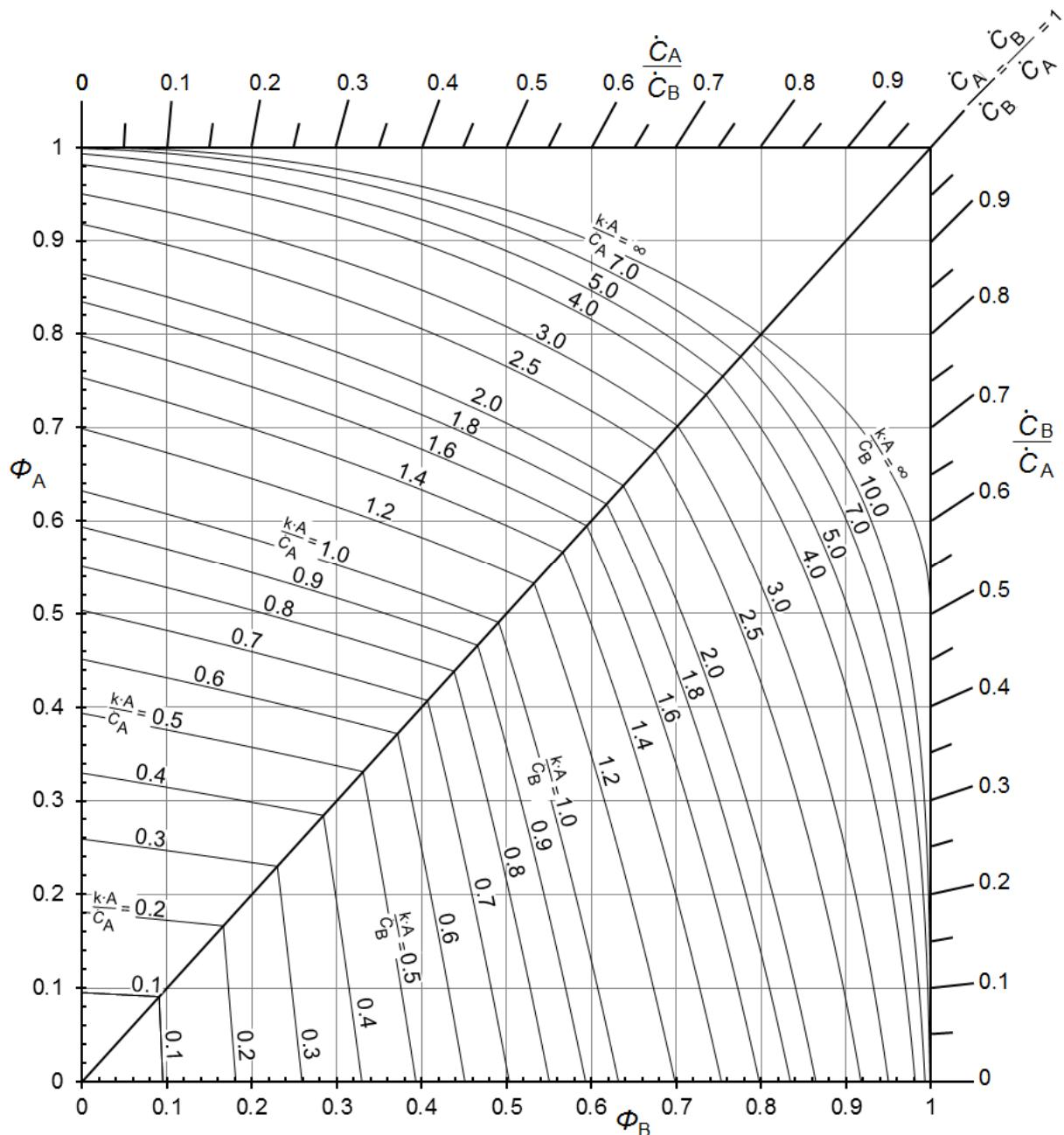


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Figure 5.25: One pass for stream 1 and four passes for stream 2 - ITYPE 23

Two passes for stream 1 and four passes for stream 2 in overall counterflow
 Calculated from VDI Heat Atlas 2010



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Figure 5.26: Two passes for stream 1 and four passes for stream 2 in overall counterflow - ITYPE 24

6. Satisfied Customers

Date: 07/2019

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2019

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GKS Schweinfurt	06/2019
HS Zittau/Görlitz, Wirtschaftswissenschaften und Wirtschaftsingenieurwesen	06/2019
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Fels-Werke, Elbingerode	04/2019
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Eins-Energie Sachsen, Schwarzenberg	03/2019
TU Dresden, Kälte- und Kryotechnik	03/2019
ITER, St. Paul Lez Durance Cedex, France	03/2019
Fraunhofer UMSICHT, Oberhausen	03/2019
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BSH Berlin	01/2019

2018

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WIB, Dennheritz	03/2018
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Compact Kältetechnik, Dresden	12/2017
Endress + Hauser Messtechnik GmbH +Co. KG, Hannover	12/2017
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Haarslev Industries, Søndersø, Denmark	11/2017
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2016

BOGE Druckluftsysteme, Bielefeld	12/2016
BFT Planung, Aachen	11/2016
Midiplan, Bietigheim-Bissingen	11/2016
BBE Barnich IB	11/2016
Wenisch IB,	11/2016
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Planungsbüro Waidhas GmbH, Chemnitz	07/2016
EEB Enerko, Aldershoven	07/2016
IHEBA Naturenergie GmbH & Co. KG, Pfaffenhofen	07/2016
SSP Kälteplaner AG, Wolfertschwenden	07/2016
EEB ENERKO Energiewirtschaftliche Beratung GmbH, Berlin	07/2016
BOGE Kompressoren Otto BOGE GmbH & Co KG, Bielefeld	06/2016
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WULFF & UMAG Energy Solutions GmbH, Husum	03/2016
FH Bielefeld, Bielefeld	03/2016
EWT Eckert Wassertechnik GmbH, Celle	03/2016
ILK Institut für Luft- und Kältetechnik GmbH, Dresden	02/2016, 06/2016
IEV KEMA - DNV GV – Energie, Dresden	02/2016
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G.A.M. Heat GmbH, Gräfenhainichen	02/2016
Institut für Luft- und Kältetechnik, Dresden	02/2016, 05/2016, 06/2016
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INL Idaho National Laboratory, Idaho, USA	11/2016, 01/2016
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2015

EES Enerko, Aachen	12/2015
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KIT Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen	07/2015
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2014

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ULT, Löbau	12/2013
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Technical University of Regensburg	10/2013
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M&M Turbinentechnik, Bielefeld	08/2013
BEG-BHV, Bremerhaven	08/2013
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Siemens, Frankenthal	08/2013, 10/2013

		11/2013
VGB, Essen		07/2013, 11/2013
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Technical University of Deggendorf		07/2013
University of Maryland, USA		07/2013, 08/2013
University of Princeton, USA		07/2013
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IGUS GmbH, Dresden		06/2013
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Technical University of Wismar		02/2013
Technical University of Dusseldorf		02/2013
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Fichtner IT, Stuttgart		01/2013, 11/2013
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Schütz Engineering, Wadgassen		01/2013
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Oschatz GmbH, Essen		01/2013
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2012

Voith, Bayreuth	12/2012
Technical University of Munich	12/2012
Dillinger Huette	12/2012
University of Stuttgart	11/2012
Siemens, Muehlheim	11/2012
Sennheiser, Hannover	11/2012
Oschatz GmbH, Essen	10/2012
Fichtner IT, Stuttgart	10/2012, 11/2012
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Weghaus Consulting Engineers, Wuerzburg	08/2012
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M & M, Bielefeld	03/2012
Sennheiser, Wedemark	03/2012
SPG, Montreuil Cedex, France	02/2012
German Destilation, Sprendlingen	02/2012
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airinotec, Bayreuth	01/2012, 07/2012
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VPC, Vetschau	01/2012
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2011

XRG-Simulation, Hamburg	12/2011
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RWTH Aachen University	07/2011, 08/2011
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Caliqua, Basel, Switzerland	06/2011
Technical University of Freiberg	06/2011
Fichtner IT Consulting, Stuttgart	05/2011, 06/2011, 08/2011
	05/2011
Salzgitter Flachstahl, Salzgitter	05/2011
Helbling Beratung & Bauplanung, Zurich, Switzerland	05/2011
INEOS, Cologne	04/2011
Enseleit Consulting Engineers, Siebigerode	04/2011
Witt Consulting Engineers, Stade	03/2011
Helbling, Zurich, Switzerland	03/2011
MAN Diesel, Copenhagen, Denmark	03/2011
AGO, Kulmbach	03/2011
University of Duisburg	03/2011, 06/2011
CCP, Marburg	03/2011
BASF, Ludwigshafen	02/2011
ALSTOM Power, Baden, Switzerland	02/2011
Universität der Bundeswehr, Munich	02/2011
Calorifer, Elgg, Switzerland	01/2011
STRABAG, Vienna, Austria	01/2011
TUEV Sued, Munich	01/2011

ILK Dresden	01/2011
Technical University of Dresden	01/2011, 05/2011
	06/2011, 08/2011

2010

Umweltinstitut Neumarkt	12/2010
YIT Austria, Vienna, Austria	12/2010
MCI Innsbruck, Austria	12/2010
University of Stuttgart	12/2010
HS Cooler, Wittenburg	12/2010
Visteon, Novi Jicin, Czech Republic	12/2010
CompuWave, Brunntal	12/2010
Stadtwerke Leipzig	12/2010
MCI Innsbruck, Austria	12/2010
EVONIK Energy Services, Zwingenberg	12/2010
Caliqua, Basel, Switzerland	11/2010
Shanghai New Energy Resources Science & Technology, China	11/2010
Energieversorgung Halle	11/2010
Hochschule für Technik Stuttgart, University of Applied Sciences	11/2010
Steinmueller, Berlin	11/2010
Amberg-Weiden University of Applied Sciences	11/2010
AREVA NP, Erlangen	10/2010
MAN Diesel, Augsburg	10/2010
KRONES, Neutraubling	10/2010
Vaillant, Remscheid	10/2010
PC Ware, Leipzig	10/2010
Schubert Consulting Engineers, Weißenberg	10/2010
Fraunhofer Institut UMSICHT, Oberhausen	10/2010
Behringer Consulting Engineers, Tagmersheim	09/2010
Saacke, Bremen	09/2010
WEBASTO, Neubrandenburg	09/2010
Concordia University, Montreal, Canada	09/2010
Compañía Eléctrica de Sochagota, Bogota, Colombia	08/2010
Hannover University of Applied Sciences	08/2010
ERGION, Mannheim	07/2010
Fichtner IT Consulting, Stuttgart	07/2010
TF Design, Matieland, South Africa	07/2010
MCE, Berlin	07/2010, 12/2010
IPM, Zittau/Goerlitz University of Applied Sciences	06/2010
TUEV Sued, Dresden	06/2010
RWE IT, Essen	06/2010
Glen Dimplex, Kulmbach	05/2010, 07/2010 10/2010
Hot Rock, Karlsruhe	05/2010
Darmstadt University of Applied Sciences	05/2010
Voith, Heidenheim	04/2010
CombTec, Zittau	04/2010
University of Glasgow, Great Britain	04/2010

Universitaet der Bundeswehr, Munich	04/2010
Technical University of Hamburg-Harburg	04/2010
Vattenfall Europe, Berlin	04/2010
HUBER Consulting Engineers, Berching	04/2010
VER, Dresden	04/2010
CCP, Marburg	03/2010
Offenburg University of Applied Sciences	03/2010
Technical University of Berlin	03/2010
NIST Boulder CO, USA	03/2010
Technical University of Dresden	02/2010
Siemens Energy, Nuremberg	02/2010
Augsburg University of Applied Sciences	02/2010
ALSTOM Power, Baden, Switzerland	02/2010, 05/2010
MIT Massachusetts Institute of Technology Cambridge MA, USA	02/2010
Wieland Werke, Ulm	01/2010
Siemens Energy, Goerlitz	01/2010, 12/2010
Technical University of Freiberg	01/2010
ILK, Dresden	01/2010, 12/2010
Fischer-Uhrig Consulting Engineers, Berlin	01/2010

2009

ALSTOM Power, Baden, Schweiz	01/2009, 03/2009 05/2009
Nordostschweizerische Kraftwerke AG, Doettingen, Switzerland	02/2009
RWE, Neurath	02/2009
Brandenburg University of Technology, Cottbus	02/2009
Hamburg University of Applied Sciences	02/2009
Kehrein, Moers	03/2009
EPP Software, Marburg	03/2009
Bernd Münstermann, Telgte	03/2009
Suedzucker, Zeitz	03/2009
CPP, Marburg	03/2009
Gelsenkirchen University of Applied Sciences	04/2009
Regensburg University of Applied Sciences	05/2009
Gatley & Associates, Atlanta, USA	05/2009
BOSCH, Stuttgart	06/2009, 07/2009
Dr. Nickolay, Consulting Engineers, Gommersheim	06/2009
Ferrostal Power, Saarlouis	06/2009
BHR Bilfinger, Essen	06/2009
Intraserv, Wiesbaden	06/2009
Lausitz University of Applied Sciences, Senftenberg	06/2009
Nuernberg University of Applied Sciences	06/2009
Technical University of Berlin	06/2009
Fraunhofer Institut UMSICHT, Oberhausen	07/2009
Bischoff, Aurich	07/2009
Fichtner IT Consulting, Stuttgart	07/2009
Techsoft, Linz, Austria	08/2009
DLR, Stuttgart	08/2009

Wienstrom, Vienna, Austria	08/2009
RWTH Aachen University	09/2009
Vattenfall, Hamburg	10/2009
AIC, Chemnitz	10/2009
Midiplan, Bietigheim-Bissingen	11/2009
Institute of Air Handling and Refrigeration ILK, Dresden	11/2009
FZD, Rossendorf	11/2009
Techgroup, Ratingen	11/2009
Robert Sack, Heidelberg	11/2009
EC, Heidelberg	11/2009
MCI, Innsbruck, Austria	12/2009
Saacke, Bremen	12/2009
ENERKO, Aldenhoven	12/2009

2008

Pink, Langenwang	01/2008
Fischer-Uhrig, Berlin	01/2008
University of Karlsruhe	01/2008
MAAG, Kuesnacht, Switzerland	02/2008
M&M Turbine Technology, Bielefeld	02/2008
Lentjes, Ratingen	03/2008
Siemens Power Generation, Goerlitz	04/2008
Evonik, Zwingenberg (general EBSILON program license)	04/2008
WEBASTO, Neubrandenburg	04/2008
CFC Solutions, Munich	04/2008
RWE IT, Essen	04/2008
Rerum Cognitio, Zwickau	04/2008, 05/2008
ARUP, Berlin	05/2008
Research Center, Karlsruhe	07/2008
AWEKO, Neukirch	07/2008
Technical University of Dresden, Professorship of Building Services	07/2008
Technical University of Cottbus, Chair in Power Plant Engineering	07/2008, 10/2008
Ingersoll-Rand, Unicov, Czech Republic	08/2008
Technip Benelux BV, Zoetermeer, Netherlands	08/2008
Fennovoima Oy, Helsinki, Finland	08/2008
Fichtner Consulting & IT, Stuttgart	09/2008
PEU, Espenhain	09/2008
Popty, Dresden	09/2008
WINGAS, Kassel	09/2008
TUEV Sued, Dresden	10/2008
Technical University of Dresden, Professorship of Thermic Energy Machines and Plants	10/2008, 11/2008
AWTEC, Zurich, Switzerland	11/2008
Siemens Power Generation, Erlangen	12/2008

2007

Audi, Ingolstadt	02/2007
ANO Abfallbehandlung Nord, Bremen	02/2007
TUEV NORD SysTec, Hamburg	02/2007
VER, Dresden	02/2007
Technical University of Dresden, Chair in Jet Propulsion Systems	02/2007
Redacom, Nidau, Switzerland	02/2007
Universität der Bundeswehr, Munich	02/2007
Maxxtec, Sinsheim	03/2007
University of Rostock, Chair in Technical Thermodynamics	03/2007
AGO, Kulmbach	03/2007
University of Stuttgart, Chair in Aviation Propulsions	03/2007
Siemens Power Generation, Duisburg	03/2007
ENTHAL Haustechnik, Rees	05/2007
AWECO, Neukirch	05/2007
ALSTOM, Rugby, Great Britain	06/2007
SAAS, Possendorf	06/2007
Grenzebach BSH, Bad Hersfeld	06/2007
Reichel Engineering, Haan	06/2007
Technical University of Cottbus, Chair in Power Plant Engineering	06/2007
Voith Paper Air Systems, Bayreuth	06/2007
Egger Holzwerkstoffe, Wismar	06/2007
Tissue Europe Technologie, Mannheim	06/2007
Dometic, Siegen	07/2007
RWTH Aachen University, Institute for Electrophysics	09/2007
National Energy Technology Laboratory, Pittsburg, USA	10/2007
Energieversorgung Halle	10/2007
AL-KO, Jettingen	10/2007
Grenzebach BSH, Bad Hersfeld	10/2007
Wiesbaden University of Applied Sciences, Department of Engineering Sciences	10/2007
Endress+Hauser Messtechnik, Hannover	11/2007
Munich University of Applied Sciences, Department of Mechanical Engineering	11/2007
Rerum Cognitio, Zwickau	12/2007
Siemens Power Generation, Erlangen	11/2007
University of Rostock, Chair in Technical Thermodynamics	11/2007, 12/2007

2006

STORA ENSO Sachsen, Eilenburg	01/2006
Technical University of Munich, Chair in Energy Systems	01/2006
NUTEC Engineering, Bisikon, Switzerland	01/2006, 04/2006
Conwel eco, Bochov, Czech Republic	01/2006
Offenburg University of Applied Sciences	01/2006
KOCH Transporttechnik, Wadgassen	01/2006
BEG Bremerhaven Entorgungsgeellschaft	02/2006
Deggendorf University of Applied Sciences, Department of Mechanical Engineering and Mechatronics	02/2006
University of Stuttgart,	02/2006

Department of Thermal Fluid Flow Engines	
Technical University of Munich,	02/2006
Chair in Apparatus and Plant Engineering	
Energietechnik Leipzig (company license),	02/2006
Siemens Power Generation, Erlangen	02/2006, 03/2006
RWE Power, Essen	03/2006
WAETAS, Pobershau	04/2006
Siemens Power Generation, Goerlitz	04/2006
Technical University of Braunschweig,	04/2006
Department of Thermodynamics	
EnviCon & Plant Engineering, Nuremberg	04/2006
Brassel Engineering, Dresden	05/2006
University of Halle-Merseburg,	05/2006
Department of USET Merseburg incorporated society	
Technical University of Dresden,	05/2006
Professorship of Thermic Energy Machines and Plants	
Fichtner Consulting & IT Stuttgart (company licenses and distribution)	05/2006
Suedzucker, Ochsenfurt	06/2006
M&M Turbine Technology, Bielefeld	06/2006
Feistel Engineering, Volkach	07/2006
ThyssenKrupp Marine Systems, Kiel	07/2006
Caliqua, Basel, Switzerland (company license)	09/2006
Atlas-Stord, Rodovre, Denmark	09/2006
Konstanz University of Applied Sciences, Course of Studies Construction and Development	10/2006
Siemens Power Generation, Duisburg	10/2006
Hannover University of Applied Sciences, Department of Mechanical Engineering	10/2006
Siemens Power Generation, Berlin	11/2006
Zikesch Armaturentechnik, Essen	11/2006
Wismar University of Applied Sciences, Seafaring Department	11/2006
BASF, Schwarzeide	12/2006
Enertech Energie und Technik, Radebeul	12/2006

2005

TUEV Nord, Hannover	01/2005
J.H.K Plant Engineering and Service, Bremerhaven	01/2005
Electrowatt-EKONO, Zurich, Switzerland	01/2005
FCIT, Stuttgart	01/2005
Energietechnik Leipzig (company license)	02/2005, 04/2005
	07/2005
eta Energieberatung, Pfaffenhofen	02/2005
FZR Forschungszentrum, Rossendorf/Dresden	04/2005
University of Saarbruecken	04/2005
Technical University of Dresden	04/2005
Professorship of Thermic Energy Machines and Plants	
Grenzebach BSH, Bad Hersfeld	04/2005
TUEV Nord, Hamburg	04/2005

Technical University of Dresden, Waste Management	05/2005
Siemens Power Generation, Goerlitz	05/2005
Duesseldorf University of Applied Sciences,	05/2005
Department of Mechanical Engineering and Process Engineering	
Redacom, Nidau, Switzerland	06/2005
Dumas Verfahrenstechnik, Hofheim	06/2005
Alensys Engineering, Erkner	07/2005
Stadtwerke Leipzig	07/2005
SaarEnergie, Saarbruecken	07/2005
ALSTOM ITC, Rugby, Great Britain	08/2005
Technical University of Cottbus, Chair in Power Plant Engineering	08/2005
Vattenfall Europe, Berlin (group license)	08/2005
Technical University of Berlin	10/2005
Basel University of Applied Sciences,	10/2005
Department of Mechanical Engineering, Switzerland	
Midiplan, Bietigheim-Bissingen	11/2005
Technical University of Freiberg, Chair in Hydrogeology	11/2005
STORA ENSO Sachsen, Eilenburg	12/2005
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KEMA IEV, Dresden	12/2005

2004

Vattenfall Europe (group license)	01/2004
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University of Stuttgart, Institute of Thermodynamics and Heat Engineering	02/2004
MAN B&W Diesel A/S, Copenhagen, Denmark	02/2004
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Ulm University of Applied Sciences	03/2004
Visteon, Kerpen	03/2004, 10/2004
Technical University of Dresden,	
Professorship of Thermic Energy Machines and Plants	04/2004
Rerum Cognitio, Zwickau	04/2004
University of Saarbruecken	04/2004
Grenzebach BSH, Bad Hersfeld	04/2004
SOFBID Zwingenberg (general EBSILON program license)	04/2004
EnBW Energy Solutions, Stuttgart	05/2004
HEW-Kraftwerk, Tiefstack	06/2004
h s energieanlagen, Freising	07/2004
FCIT, Stuttgart	08/2004
Physikalisch Technische Bundesanstalt (PTB), Braunschweig	08/2004
Mainova Frankfurt	08/2004
Rietschle Energieplaner, Winterthur, Switzerland	08/2004
MAN Turbo Machines, Oberhausen	09/2004
TUEV Sued, Dresden	10/2004
STEAG Kraftwerk, Herne	10/2004, 12/2004
University of Weimar	10/2004
energeticals (e-concept), Munich	11/2004
SorTech, Halle	11/2004

Enertech EUT, Radebeul (company license)	11/2004
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STORA ENSO Sachsen, Eilenburg	12/2004
Technical University of Cottbus, Chair in Power Plant Engineering	12/2004
Freudenberg Service, Weinheim	12/2004

2003

Paper Factory, Utzenstorf, Switzerland	01/2003
MAB Plant Engineering, Vienna, Austria	01/2003
Wulff Energy Systems, Husum	01/2003
Technip Benelux BV, Zoetermeer, Netherlands	01/2003
ALSTOM Power, Baden, Switzerland	01/2003, 07/2003
VER, Dresden	02/2003
Rietschle Energieplaner, Winterthur, Switzerland	02/2003
DLR, Leupholdhausen	04/2003
Emden University of Applied Sciences, Department of Technology	05/2003
Pettersson+Ahrends, Ober-Moerlen	05/2003
SOFBID ,Zwingenberg (general EBSILON program license)	05/2003
Ingenieurbuero Ostendorf, Gummersbach	05/2003
TUEV Nord, Hamburg	06/2003
Muenstermann GmbH, Telgte-Westbevern	06/2003
University of Cali, Colombia	07/2003
Atlas-Stord, Rodovre, Denmark	08/2003
ENERKO, Aldenhoven	08/2003
STEAG RKB, Leuna	08/2003
eta Energieberatung, Pfaffenhofen	08/2003
exergie, Dresden	09/2003
AWTEC, Zurich, Switzerland	09/2003
Energie, Timelkam, Austria	09/2003
Electrowatt-EKONO, Zurich, Switzerland	09/2003
LG, Annaberg-Buchholz	10/2003
FZR Forschungszentrum, Rossendorf/Dresden	10/2003
EnviCon & Plant Engineering, Nuremberg	11/2003
Visteon, Kerpen	11/2003
VEO Vulkan Energiewirtschaft Oderbruecke, Eisenhuettenstadt	11/2003
Stadtwerke Hannover	11/2003
SaarEnergie, Saarbruecken	11/2003
Fraunhofer-Gesellschaft, Munich	12/2003
Erfurt University of Applied Sciences, Department of Supply Engineering	12/2003
SorTech, Freiburg	12/2003
Mainova, Frankfurt	12/2003
Energieversorgung Halle	12/2003

2002

Hamilton Medical AG, Rhaeuens, Switzerland	01/2002
Bochum University of Applied Sciences, Department of Thermo- and Fluid Dynamics	01/2002

SAAS, Possendorf/Dresden	02/2002
Siemens, Karlsruhe	02/2002
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Fischer-Uhrig Engineering, Berlin	08/2002
Fichtner Consulting & IT, Stuttgart	08/2002
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Stadtwerke Hannover	09/2002
Siemens Power Generation, Goerlitz	10/2002
Energieversorgung Halle (company license)	10/2002
Bayer, Leverkusen	11/2002
Dillinger Huette, Dillingen	11/2002
G.U.N.T. Geraetebau, Barsbuettel	12/2002
(general license and training test benches)	
VEAG, Berlin (group license)	12/2002

2001

ALSTOM Power, Baden, Switzerland	01/2001, 06/2001
	12/2001
KW2 B. V., Amersfoot, Netherlands	01/2001, 11/2001
Eco Design, Saitamaken, Japan	01/2001
M&M Turbine Technology, Bielefeld	01/2001, 09/2001
MVV Energie, Mannheim	02/2001
Technical University of Dresden, Department of Power Machinery and Plants	02/2001
PREUSSAG NOELL, Wuerzburg	03/2001
Fichtner Consulting & IT Stuttgart	04/2001
(company licenses and distribution)	
Muenstermann GmbH, Telgte-Westbevern	05/2001
SaarEnergie, Saarbruecken	05/2001
Siemens, Karlsruhe	08/2001
(general license for the WinIS information system)	
Neusiedler AG, Ulmerfeld, Austria	09/2001
h s energieanlagen, Freising	09/2001
Electrowatt-EKONO, Zurich, Switzerland	09/2001
IPM Zittau/Goerlitz University of Applied Sciences (general license)	10/2001

eta Energieberatung, Pfaffenhofen	11/2001
ALSTOM Power Baden, Switzerland	12/2001
VEAG, Berlin (group license)	12/2001

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SOFBID, Zwingenberg	01/2000
(general EBSILON program license)	
AG KKK - PGW Turbo, Leipzig	01/2000
PREUSSAG NOELL, Wuerzburg	01/2000
M&M Turbine Technology, Bielefeld	01/2000
IBR Engineering Reis, Nittendorf-Undorf	02/2000
GK, Hannover	03/2000
KRUPP-UHDE, Dortmund (company license)	03/2000
UMAG W. UDE, Husum	03/2000
VEAG, Berlin (group license)	03/2000
Thinius Engineering, Erkrath	04/2000
SaarEnergie, Saarbruecken	05/2000, 08/2000
DVO Data Processing Service, Oberhausen	05/2000
RWTH Aachen University	06/2000
VAUP Process Automation, Landau	08/2000
Knuerr-Lommatec, Lommatsch	09/2000
AVACON, Helmstedt	10/2000
Compania Electrica, Bogota, Colombia	10/2000
G.U.N.T. Geraetebau, Barsbuettel	11/2000
(general license for training test benches)	
Steinhaus Informationssysteme, Datteln	12/2000
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1999

Bayernwerk, Munich	01/1999
DREWAG, Dresden (company license)	02/1999
KEMA IEV, Dresden	03/1999
Regensburg University of Applied Sciences	04/1999
Fichtner Consulting & IT, Stuttgart	07/1999
(company licenses and distribution)	
Technical University of Cottbus, Chair in Power Plant Engineering	07/1999
Technical University of Graz, Department of Thermal Engineering, Austria	11/1999
Ostendorf Engineering, Gummersbach	12/1999

1998

Technical University of Cottbus, Chair in Power Plant Engineering	05/1998
Fichtner Consulting & IT (CADIS information systems) Stuttgart	05/1998
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M&M Turbine Technology Bielefeld	06/1998
B+H Software Engineering Stuttgart	08/1998
Alfa Engineering, Switzerland	09/1998
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SCA Hygiene Products, Munich	10/1998
RWE Energie, Neurath	10/1998
Wilhelmshaven University of Applied Sciences	10/1998
BASF, Ludwigshafen (group license)	11/1998
Energieversorgung, Offenbach	11/1998

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Gerb, Dresden	06/1997
Siemens Power Generation, Goerlitz	07/1997