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# ASSESSMENT OF SELECTED FILM-BOILING PREDICTION METHODS

by

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## ABSTRACT

Seven film-boiling prediction methods have been assessed with a large film-boiling heat transfer database, which contains 46,068 data points. The assessment is performed in two ways: (1) with all fully developed film-boiling data, and (2) with the complete film-boiling database. The prediction accuracy of these methods is presented in terms of average and root-mean-square errors for each data set. The detailed prediction accuracy in each sub-parametric region has also been presented to show the applicable range of each method. The assessment result shows that the film-boiling look-up table provides the best overall prediction accuracy. The Köhler-Hein model provides reasonable prediction accuracy for the film-boiling heat-transfer coefficient over a wide range of flow conditions. Other models are either less accurate or are applicable within a narrower range of conditions than the look-up table and the Köhler-Hein model.

## NOMENCLATURE

| | |
|---|---|
| D | tube inside diameter (m) |
| G | mass flux (kg $m^{-2}$ $s^{-1}$) |
| h | heat transfer coefficient (kW $m^{-2}$ $K^{-1}$) |
| H | enthalpy (J $kg^{-1}$) |
| $H_{fg}$ | heat of evaporation = $H_g$ - $H_f$ (J $kg^{-1}$) |
| k | thermal conductivity (kW $m^{-1}$ $K^{-1}$) |
| Nu | Nusselt number = h D / k |
| P | pressure (Pa = N $m^{-2}$, bar = $10^5$ N $m^{-2}$) |
| Pr | Prandtl number = $\mu$ Cp / k |
| q | surface heat flux (kW $m^{-2}$) |
| Re | Reynolds number = G D / $\mu$ |
| T | temperature (K) |
| *x* | thermodynamic quality |

**Greek symbols**

| | |
|---|---|
| $\alpha$ | void fraction |
| $\rho$ | fluid density (kg $m^{-3}$) |
| $\mu$ | dynamic viscosity N s $m^{-2}$ = kg $m^{-1}$ $s^{-1}$) |

**Subscripts**

| | |
|---|---|
| a | actual |
| DO | dryout condition |
| e | equilibrium conditions |
| f | saturated liquid |
| g | saturated vapor |
| sat | saturation |
| tp | two-phase |
| W | wall |

# 1 INTRODUCTION

The prediction of maximum fuel sheath temperature is required for safety analyses of postulated accident scenarios (such as the loss of regulation, loss of flow, small loss-of-coolant, and loss of Class IV power) in nuclear power reactors. Under these scenarios, the sheath-to-coolant heat transfer rate deteriorates and the heated sheath may become temporarily too hot for liquid to maintain contact. The heat transfer regime under these conditions is known as the film-boiling regime, and the corresponding heat transfer is referred to as film-boiling heat transfer.

Film-boiling heat transfer in a fuel bundle is complex, particularly under postulated accident scenarios where flow parameters vary considerably. The current approach in safety analyses employs the tube-data-based correlation to predict the fully developed film-boiling heat transfer coefficient, and applies a bundle-data-based modification factor to account for geometry and developing-flow effects. Therefore, a good tube-data-based correlation is essential to improve the prediction accuracy of film-boiling heat transfer coefficients in bundles.

A large number of prediction methods for film-boiling heat transfer in tubes have been developed over the past 50 years. These methods are applicable only to a limited range of flow conditions, due to their empirical or semi-empirical nature. Furthermore, extrapolation of these methods beyond their development database is generally not recommended, because of the limitation in the closure relationships. This limitation has complicated the choice of a prediction method for safety analyses.

The objective of this study is to assess the existing film-boiling heat transfer prediction methods by comparing them with a large film-boiling database, and to provide users with detailed information concerning prediction error distributions, through which the advantages and limitations of each film-boiling heat transfer model or correlation are revealed.

# 2 DESCRIPTION OF SELECTED PREDICTION METHODS

## 2.1 General

Film-boiling models and correlations have been derived using different databases, based on different interfacial heat transfer assumptions; hence, they have different application ranges. These models and correlations can be generally categorized into two groups: thermal equilibrium, and thermal non-equilibrium.

*Thermal equilibrium* correlations assume that the liquid is in thermal equilibrium with the vapor, and that the heated surface is cooled by forced convection to the vapor only. These correlations are basically forced convection correlations, where the vapor velocity is evaluated by assuming homogeneous flow. Therefore, these correlations usually have the following form:

$$Nu_g = a\,\mathrm{Re}_{tp}^{b}\,\mathrm{Pr}_g^{c}\,Y \tag{1}$$

where $a$, $b$, and $c$ are constants, and $Y$ is a correction function. $\mathrm{Re}_{tp}$ is the two-phase Reynolds number, defined as

$$Re_{tp} = Re_g\left[x_e + \frac{\rho_g}{\rho_f}\left(1 - x_e\right)\right] \tag{2}$$

in which $Re_g$ is the vapor Reynolds number, defined as $GD/\mu_g$ , and $x_e$ is the equilibrium quality. Examples of equilibrium correlations are those given by Dougall and Rohsenow (1963) and Miropolskiy (1963).

*Thermal non-equilibrium* models or correlations assume a large degree of vapor superheat. In these types of models or correlations, wall-vapor heat transfer is usually calculated based on the pure vapor convective heat transfer correlation, in which actual quality ($x_a$) rather than equilibrium quality is used. The actual quality is evaluated using various theoretical or empirical models or correlations. The vapor temperature is subsequently calculated from the actual quality, that is,

$$\frac{x_a}{x_e} = \frac{H_{fg}}{H_v(p,T_v) - H_f} \tag{3}$$

where $H$ is the fluid enthalpy. Examples of thermal non-equilibrium prediction methods are those given by Groeneveld-Delorme (1976), Köhler-Hein (1986), Chen-Chen (1998), and Shah-Siddiqui (2000).

In general, thermal equilibrium correlations agree with experimental data only under high pressure and high mass-flux conditions, where the vapor temperature is often close to the saturation temperature because of very efficient liquid-vapor heat exchange. Under low flow conditions, inefficient interfacial heat transfer results in very high vapor superheats; hence, equilibrium correlations are not appropriate.

To further improve prediction accuracy, Leung et al. (1996) and Kirillov et al. (1996) have proposed the use of a film-boiling look-up table as an alternative to the film-boiling models and correlations. The look-up table is basically a normalized database of heat transfer coefficients for discrete values of pressure, mass flux, quality, and heat flux.

In this paper, seven film-boiling prediction methods were assessed, by comparing them with a large film-boiling database. The selected prediction methods in this assessment are those that are frequently cited or recommended by researchers, and that are claimed to be accurate over wide parametric ranges.

## 2.2 Description of film-boiling prediction methods

Miropolskiy (1963) equation: The Miropolskiy equation is a thermal equilibrium equation, which is very similar to the Dittus-Boelter (1930) equation. The two-phase Reynolds number is employed, and a correction factor ($Y$) is applied to account for two-phase flow conditions and to improve prediction accuracy. The Prandtl number exponent was modified from 0.4 to 0.8, and the Prandtl number was based on wall temperature rather than bulk temperature. The range of application of this equation is

$P$: 4050–22300 kPa
$G$: 400–2000 kg/m$^2$s
$x_e$: 0–1.04

Dougall-Rohsenow (1963) equation: The Dougall-Rohsenow equation also assumes complete thermodynamic equilibrium between the phases. It is a modified form of the Dittus-Boelter (1930) equation, which also uses the two-phase Reynolds number. In this equation all the fluid properties are evaluated at the saturation temperature. It is expected that the performance of this equation will start to deteriorate at higher qualities, because there is no longer enough liquid present to maintain the bulk of the vapor at the saturation temperature. Bailey (1977) applied the film temperature to evaluate the fluid properties in the Dougall-Rohsenow equation. This approach improved the prediction accuracy at high quality conditions. At low qualities, the prediction accuracy of the equation deteriorates considerably, because the droplet size and phase distribution deviate significantly from the homogeneous values. Therefore, applying the equation to low quality regions is not recommended.

Groeneveld-Delorme (1976) equation: The Groeneveld-Delorme equation was derived in the 1970s with a limited database. Non-equilibrium was taken into account with an empirical correlation; subsequently, the vapor superheat was evaluated. Heat transfer was then determined using the calculated vapor superheat, in conjunction with the modified Hadaller superheated steam correlation (Hadaller et al. 1969). The database covered the following range of flow conditions:

$P < 20500$ kPa
$G > 270$ kg/m$^2$s
$x_e > 0$

Köhler-Hein (1986) model: The Köhler-Hein model is a semi-empirical model derived with an energy balance between phases. The model assumes that thermal non-equilibrium develops between the phases downstream of the dryout point. The non-equilibrium eventually reaches a maximum. Downstream of the maximum non-equilibrium point, the thermal non-equilibrium is assumed to be “fully developed”, and the wall and vapor temperatures no longer depend on the dryout quality, $x_{DO}$, or dryout location. This point is characterized by a maximum wall temperature (or a minimum heat transfer coefficient), as shown in Figure 1.

The main contributions of the Köhler-Hein model are the prediction of (*i*) the boundary of the fully developed non-equilibrium region, and (*ii*) the vapor temperature in the fully developed region. After determining the vapor temperature, the wall temperature is calculated using the Gnielinski (1976) equation for single-phase flow. To determine the boundary of the fully developed non-equilibrium region, $x_{DO}$ is required. The recommended parameter ranges are

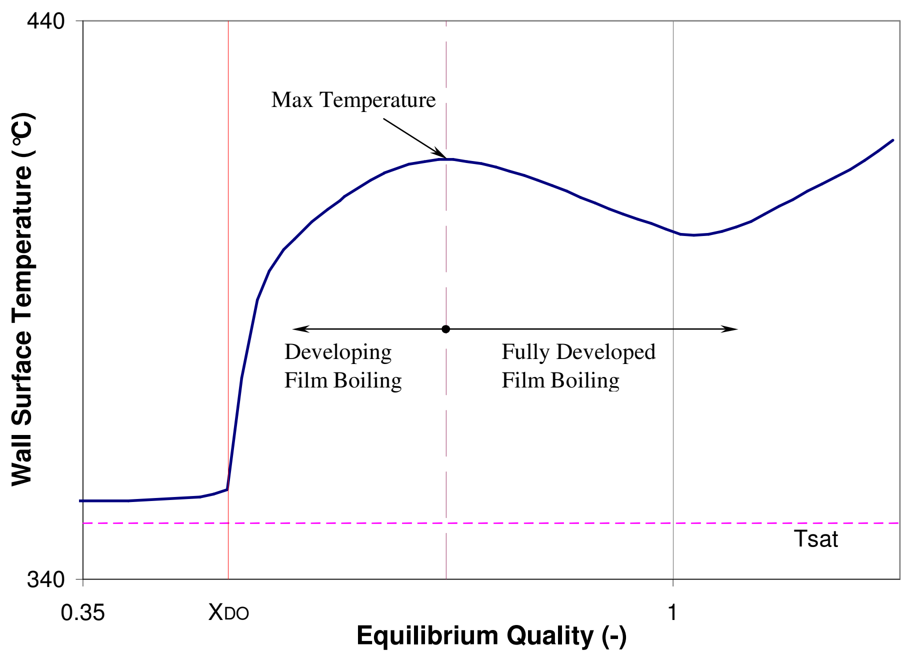


Figure 1: Illustration of the Axial Temperature Distribution

*P*: > 3000 kPa
*G*: > 300 kg/m$^2$s
$x_e$: > 0.2

Chen-Chen (1998) model: The Chen-Chen model uses a tabular method to evaluate the thermal non-equilibrium factor, *k*. The Plummer (1974) equation was adopted to represent the degree of thermal non-equilibrium, defined as

$$k = \frac{x_a - x_{DO}}{x_e - x_{DO}} \tag{4}$$

The tabulation was based on their own database, which includes vapor temperature measurements. After the actual quality ($x_a$), and subsequently, the vapor temperature ($T_v$) are determined, the wall temperature is calculated by assuming pure convective heat transfer between the heated wall and the superheated vapor. In the Chen-Chen model, the convection heat transfer coefficient for pure steam was calculated with their own correlation derived from their experiment of convection steam in tubes (Chen-Chen 1996). The independent parameters of the Chen-Chen model are pressure, mass flux, equilibrium quality ($x_e$), and dryout quality ($x_{DO}$). Chen-Chen's method covers the following ranges:
*P*: 100–5800 kPa
*G*: 23–1462 kg/m$^2$s
$x_e$: 0–1.36

Extending this model to higher pressure and higher mass flux ranges is permitted, as the non-equilibrium is known to disappear under such conditions.

Shah-Siddiqui (2000) model: The Shah-Siddiqui model is basically an updated version of the Shah (1980) graphical approach, using equations instead of graphs. To evaluate the non-equilibrium, the actual quality ($x_a$) was predicted from empirical correlations. The vapor temperature was then determined, and the wall temperature was subsequently calculated using a method similar to the Chen-Chen (1998) model. The Dittus-Boelter (1930) equation and the Hadaller-Banerjee (1969) equation were used to calculate the vapor single-phase heat transfer coefficient. In addition to pressure, mass flux, equilibrium quality ($x_e$) and dryout quality ($x_{DO}$), the boiling number (*Bo*) and Froude number (*Fr*) were also required in the calculation. The Shah-Siddiqui prediction method was applied to several fluids and provided credible results over a wide range of conditions. The recommended range of application for film boiling in water-cooled tubes is
*P*: 100–21500 kPa
*G*: 4–5176 kg/m$^2$s
*D*: 1.1–24.3 mm
$x_e$: 0.1–2.4

2001 Look-up table: The film-boiling look-up table to be assessed in this study is the PDO-LUT-2001 version (Groeneveld et al. 2002), which was developed based on 21,131 fully developed film-boiling data. The look-up table is framed on discrete pressure, mass flux, quality and wall superheat, and thus is a four-dimensional matrix containing 29,744 entries for the film-boiling heat transfer coefficient. The table predicts the heat transfer coefficient based on a given pressure, mass flux, quality, and wall superheat. The application range of the look-up table is

$P$: 100–20,000 kPa
$G$: 0–7000 kg/m$^2$s
$x_e$: -0.2–2.0
Tw-Tsat: 50–1200 K.

## 3 FILM-BOILING DATABASE

A large film-boiling database has recently been compiled from 39 film-boiling datasets (Vasic et al. 2000). The database contains a total of 77,234 data points. Table 1 provides the ranges of conditions of the film-boiling database. All references related to the datasets are given in Vasic et al. (2000).

Each dataset was subject to a screening procedure to remove questionable data points. The screening criteria are 100 kPa ≤ P ≤ 20,000 kPa, 0 kg/m$^2$s ≤ G ≤ 7000 kg/m$^2$s, -0.2 ≤ $x$ ≤ 2.0, 2.5 mm ≤ D ≤ 24.7 mm, $T_w - T_{sat} \geq 50$ K, and $T_w \geq T_{min}$, where $T_{min}$ is the minimum film-boiling temperature, calculated using the Groeneveld-Stewart correlation (Groeneveld and Stewart 1982). As a result, 46,068 data points were considered to be reliable within the flow parameter ranges of interest.

To analyze the film-boiling data, the screened database was further divided into two groups: fully developed film-boiling data, and developing film-boiling data, following the definition of Köhler and Hein (Köhler-Hein 1986), as described above and shown in Figure 1. It can be inferred that the heat transfer of fully developed flow film boiling is no longer affected by the dryout location, while in the developing film-boiling region, heat transfer depends on dryout conditions. Hence, for the developing film-boiling region, an additional parameter is needed, which is related to the film-boiling length, or $(x - x_{DO})$. Based on above definition, 19,113 data points (about 42%) were considered as fully developed film-boiling data, and the others as developing film-boiling data.

## 4 COMPARISON RESULTS

Comparisons of the seven models and/or equations were made with the combined film-boiling database (46,068 points) and the fully developed film-boiling database (19,113 points). In the comparisons the models and/or equations were applied to the parametric range covered by the database. The models were then assessed based on prediction error[1] information for each dataset, and each parameter sub-region.

A summary of the comparison results is listed in Table 2. The 2001 film-boiling look-up table (Groeneveld et al. 2002) provides the best prediction accuracy for the fully developed film-boiling database. This is understandable, because the look-up table is a normalization of the fully developed film-boiling database. The root-mean-square (RMS) error of the table prediction, compared with the combined film-boiling database, is about 20% higher than that compared with the fully developed film-boiling database, while the corresponding average error changed from 1.73% to –1.96%. It can be inferred that developing film boiling has a strong impact on film-boiling heat transfer, and that the 2001 film-boiling look-up table underpredicts the developing

[1] Error = (predicted – measured) / measured x 100%

film-boiling heat transfer coefficients. The Köhler-Hein model is also able to predict the film-boiling heat transfer coefficients with relatively good accuracy. Detailed results are given in the following sections.

### 4.1 Comparison based on datasets

Detailed error distributions of the selected prediction methods, comparing each of the 39 datasets of the complete film-boiling database, are given in Table 3, and are graphically presented in Figure 2. Note that the Subbotin data were separated into 7 subsets to present the data from different test sections. Although the 2001 look-up table was derived using fully developed film-boiling data only, it performs the best among the prediction methods for the combined film-boiling database. Large errors have been observed for some individual datasets (e.g., Gottula 1985, Chen 1994). The data in these datasets were obtained at low mass fluxes. This large error is probably due to the stronger developing film-boiling effect at low flows than at high flows. A correction factor has been developed for CANDU® conditions of interest (Guo et al. 2001) to account for the developing film-boiling effect; this has further improved the prediction accuracy[2]. In general, large errors occur for all prediction methods at low pressure, low mass flux, and low quality. This can be clearly seen by comparing the models with data based on sub-regions.

### 4.2 Comparison results based on parameter sub-regions

The error distributions of the selected prediction methods in each of 64 sub-regions are given in Table 4. This comparison is based on 46,068 data points of the combined film-boiling database. The numbers of datasets and data points in each sub-region are presented, as well. This comparison result provides valuable information of how the available data are distributed and the regions where additional data are needed. It must be pointed out that all prediction methods were applied based on the same database. The intent of doing this way is to permit a direct comparison of the prediction accuracy. From the results in Table 4, one can clearly see that (1) data at low quality conditions are very scarce; (2) data at mass fluxes lower than 300 $kg/m^2s$ are limited; and (3) none of the prediction methods can predict the film-boiling heat transfer accurately at conditions of low pressure, low mass flux, and low quality. These limitations are probably because of the more complex film-boiling mechanisms, which are not fully understood and have not been modeled properly in these prediction methods.

### 4.3 Statistical comparison results

The percentage of data points of the combined and fully developed databases that have been predicted within a given error band is statistically assessed and shown in Figure 3 and Figure 4, respectively, where the percentage of data points predicted within a given error band is plotted against the error band. As can be seen, the 2001 film-boiling look-up table and the Köhler-Hein model perform the best for both databases.

Obviously, the Milopolskiy equation and the Dougall-Rohsenow equation, which are both characterized by thermal equilibrium nature, are unable to provide good predictions. These two equations are applicable only at high mass-flux conditions (i.e., beyond 2000 $kg/m^2s$), where high

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[2] The average and RMS errors are reduced from –8.26% and 18.56% to 1.61% and 12.96%, respectively, for 2,561 developing film-boiling data points in the range of CANDU interests. Detailed results are not shown due to limited space.

turbulence enhances interfacial heat transfer between the liquid phase and the vapor phase, resulting in a more equilibrium condition. Reasonable prediction accuracy has been observed for the Groeneveld-Delorme model, the Köhler-Hein model, the Chen-Chen model, and the Shah-Siddiqui model. These models include thermal non-equilibrium calculations; hence, they provide more realistic representations of the film-boiling characteristic than the thermal-equilibrium models. Among these models, the Köhler-Hein model predicts more than 70% of the data within an error range of ±30%, and more than 90% of the data within an error range of ±50%. The 2001 look-up table is the best prediction method among all assessed models, since it results in the least prediction errors and is applicable for both the combined datasets and the fully developed datasets.

## 5 CONCLUSIONS AND FINAL REMARKS

Seven film-boiling prediction methods have been assessed with 46,068 experimental data points from 39 datasets, covering the parametric ranges of $2.5 < D < 24.7$ mm; $100 < P < 20{,}000$ kPa; $0 < G < 7000$ kg/m$^2$s; $0 < q < 3238$ kW/m$^2$; $-0.2 < x < 2.0$; and $1200 > T_w - T_{sat} > 50$°C. The error distribution for each dataset and the error distribution for each parameter sub-region were presented in this work. The following conclusions were made:

- Thermal non-equilibrium prediction methods provide much better prediction accuracy than film-boiling correlations based only on thermal equilibrium conditions. This is particularly true at low pressure, low mass flux and low quality conditions, where the degree of thermal non-equilibrium is significant.
- No single prediction method is valid throughout the whole parametric range stated above.
- In general, large prediction errors rise in regions of low pressure, low mass flux, and low or negative quality.
- To improve prediction accuracy, a better understanding of film-boiling mechanisms at conditions of low pressure, low mass flux, and low quality is required.
- The 2001 film-boiling look-up table provides the best prediction accuracy among the assessed models, especially for fully developed conditions. The Köhler-Hein model is also able to predict film-boiling heat transfer with reasonable prediction accuracy.

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Table 1: Details of the University of Ottawa Film-Boiling Database for Water-Cooled Tubes

| Datasets | Experimental Points | Diameter | Pressure | Mass Flux | Heat Flux | Thermodynamic Quality | Surface Temperature |
|---|---|---|---|---|---|---|---|
| Reference (year) | (number) | (mm) | (kPa) | (kg $m^{-2}$ $s^{-1)}$ | (kW $m^{-2}$) | (-) | (°C) |
| Schmidt (1960) | 125 | 8 | 21,575 | 700 | 291 - 814 | 0.209 - 3.094 | 391 – 626 |
| Swenson (1961) | 85 | 10.4 | 20,685 | 949 - 1,356 | 297 - 580 | 0.080 - 0.980 | 378 – 498 |
| Miropolsky (1962) | 5,500 | 8 | 3,920 - 21,570 | 389 - 2,120 | 71 - 1,362 | -2.429 - 3.415 | 242 – 644 |
| Bartoletti et al. (1964) | 19 | 5.0 - 9.2 | 6,895 | 1,085 - 3,935 | 406 - 1,421 | 0.383 - 0.895 | 377 – 454 |
| Bishop et al. (1965) | 56 | 2.5 - 5.1 | 16,617 - 21,478 | 2,007 - 3,377 | 905 - 1,924 | 0.070 - 0.910 | 392 – 610 |
| Bennett et al. (1967) | 276 | 12.6 | 6,895 | 380 - 5,180 | 383 - 2,075 | 0.229 - 1.483 | 454 – 840 |
| Era et al. (1967) | 376 | 6.0 | 6,888 - 7,281 | 1,096 - 3,014 | 352 - 1,652 | 0.456 - 1.238 | 375 – 630 |
| Herkenrath et al. (1967) | 842 | 10.0 - 20.0 | 14,004 - 20,499 | 693 - 3,556 | 253 - 1,666 | -0.117 - 1.317 | 374 – 592 |
| Konkov and Zuperman (167) | 35 | 8 | 9,800 | 1,750 | 500 | 0.605 - 0.956 | 310 - 394 |
| Bailey (1972a) | 19 | 12.7 | 17, 823 - 17,996 | 668 - 2,650 | 233 - 789 | 0.391 - 0.736 | 409 - 454 |
| Bailey (1972b) | 498 | 12.8 | 16,000, 18,000 | 670 - 2,700 | 85 - 776 | 0.357 - 0.776 | 373 – 474 |
| Subbotin et al. (1973) | 35,282 | 10 | 4,900 - 19,610 | 350 - 3,000 | 45 -1,280 | 0.051 - 2.422 | 209 – 999 |
| Janssen-Kervinen (1975) | 902 | 12.6 | 641 – 7,065 | 17 - 1,024 | 23 - 992 | 0.167 - 1.634 | 239 – 727 |
| Bailey (1977) | 549 | 15 | 1,370 - 6,990 | 49 - 668 | 84 - 799 | 0.780 – 1.210 | 200 – 697 |
| Nijhawan (1980) | 962 | 14.1 | 226 – 418 | 18 – 69 | 2 - 87 | 0.072 - 0.838 | 229 – 647 |
| Barzoni et al. (1980) | 738 | 12 | 2,910 – 7,110 | 124 – 1,002 | 63 – 1,111 | 0.530 – 1.476 | 243 -767 |
| Fung (1981) | 3,224 | 11.8 - 11.9 | 89 – 145 | 50 - 497 | 24 - 257 | -0.026 - 0.138 | 362 - 1,148 |
| Stewart (1981) | 2,515 | 8.9 | 1,937 – 9,053 | 114 - 2,815 | 64 - 459 | -0.120 - 0.736 | 376 - 780 |
| Kastner et al. (1981) | 152 | 12.5 | 1,000 - 5,010 | 509 - 2,514 | 299 - 594 | 0.368 - 1.446 | 259 – 671 |
| Becker et al. (1983) | 7,007 | 10.0 - 24.7 | 2,980 - 20,100 | 496 - 3,113 | 147 - 1,295 | 0.066 - 1.651 | 374 – 722 |
| Borodin (1983) | 286 | 8.9 | 8,205 - 8,343 | 1,347 - 6,875 | 901 - 2,700 | 0.133 - 1.072 | 377 – 720 |
| Laperriere (1983) | 2,412 | 9,0 | 3,950 - 9,632 | 962 - 4,494 | 73 - 736 | -0.119 - 0.597 | 375 - 781 |
| Annunziato (1983) | 1,628 | 12.6 | 101 | 3 - 9 | 8 - 25 | -0.096 – 1.380 | 65 - 718 |
| Liu (1984) | 119 | 12.6, 12.7 | 116 - 120 | 46 - 48 | 9 – 35 | 0.813 - 1.088 | 102 – 426 |
| Gottula et al. (1985) | 1,258 | 15.7 | 290 – 790 | 12 - 19 | 3 - 43 | 0.319 - 0.870 | 175 – 788 |
| Babcock and Wilcox (1985) | 904 | 12.7 | 420 - 10,445 | 40 - 679 | 100 - 656 | 0.675 - 1.728 | 344 – 779 |
| Köhler and Hein (1986) | 1,986 | 12.5, 14 | 4,728 - 20,040 | 490 - 2,543 | 0 - 607 | -0.328 - 1.390 | 262 – 652 |
| Swinnerton et al. (1988) | 581 | 9.8 | 198 - 2,013 | 47 - 1,010 | 14 – 419 | -0.007 - 0.554 | 294 – 876 |
| Chen et al. (1988) | 105 | 7, 12 | 105 - 1,020 | 25 - 512 | 22 - 117 | -0.027 - 0.208 | 372 – 700 |
| Li (1988), Yu et al. (1988) | 419 | 11 | 150 – 1,100 | 90 - 468 | 60 - 248 | 0.239 - 1.221 | 249 – 803 |
| Chen et al. (1989) | 357 | 12 | 411 - 6,000 | 87 - 1,486 | 34 - 223 | -0.039 - 0.498 | 384 – 818 |
| Mosaad and Johhansen (1989) | 169 | 9 | 110 | 55 - 204 | 88 – 272 | -0.049 - 0.098 | 300 - 1,292 |
| Chen and Chen (1994) | 341 | 6.8, 12 | 164 - 5,840 | 91 - 423 | 82 - 285 | 0.015 - 1.036 | 406 – 784 |
| Leung (1994) | 3,463 | 5.45, 8.9 | 5,677 - 11,034 | 996 - 10,117 | 694 - 3,238 | -0.960 - 0.958 | 275 – 605 |
| Chen et al. (1996) | 2,667 | 6.8 – 12.0 | 110 - 5,830 | 24 - 1,460 | 14.6 - 488 | -0.037 - 1.305 | 364 – 828 |
| Doerffer (1997) | 1,377 | 8 | 5,872 - 11,117 | 487 - 2,059 | 563 - 2,206 | -0.328 - 1.149 | 280 – 834 |
| Complete database | 77,234 | 2.5 – 24.7 | 89 – 21,478 | 12 – 10,117 | 0 – 3,238 | -2.429 – 3.415 | 102 – 1,292 |

Table 2: Prediction Capability of Selected Prediction Methods

| Prediction methods | Complete database (46,068 points) | | Fully developed data only (19,113 points) | |
|---|---|---|---|---|
| | Avg. err. (%) | RMS err. (%) | Avg. err. (%) | RMS err. (%) |
| Miropolskiy | 41.77 | 86.86 | 54.94 | 87.51 |
| Dougall-Rohsenow | 37.57 | 66.79 | 34.13 | 53.27 |
| Groeneveld-Delorme | -0.47 | 36.98 | 13.72 | 32.42 |
| Köhler-Hein | -10.66 | 31.33 | -2.61 | 24.52 |
| Chen-Chen | 16.95 | 51.12 | 14.64 | 49.75 |
| Shah-Siddiqui | 8.78 | 33.59 | 15.61 | 32.96 |
| 2001 look-up table | -1.96 | 27.54 | 1.73 | 10.79 |

Table 3: Assessment of prediction errors of various prediction methods for each dataset of the complete database.

| No. | References (year) | | Miropolkiy | | Dougall-Rohsenow | | Groeneveld-Delorme | | Kohler-Hein | | Chen-Chen | | Shah-Seddiqui | | Look-up Table | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | # of data | Avr. Err | Rms Err | Avr. Err | Rms Err | Avr. Err | Rms Err | Avr. Err | Rms Err | Avr. Err | Rms Err | Avr. Err | Rms Err | Avr. Err | Rms Err |
| 1 | Schmidt (1960) | 0 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 2 | Swenson (1961) | 0 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 3 | Miropolsky (1962) | 1302 | 25.89 | 41.15 | 4.16 | 19.71 | -8.54 | 19.72 | -24.32 | 28.34 | -15.10 | 21.12 | -7.61 | 18.74 | -10.12 | 19.07 |
| 4 | Bartoletti (1964) | 0 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 5 | Bishop (1965) | 26 | 48.03 | 55.92 | -0.08 | 13.97 | -17.36 | 20.29 | -18.41 | 22.86 | -25.73 | 31.90 | 9.35 | 28.27 | 15.53 | 26.65 |
| 6 | Bennett (1967) | 276 | 7.40 | 23.82 | 22.46 | 29.78 | 0.82 | 14.30 | -9.75 | 13.19 | 7.69 | 15.47 | 8.02 | 13.24 | -4.28 | 8.15 |
| 7 | Era (1967) | 251 | 14.96 | 21.48 | 24.24 | 27.88 | -4.11 | 14.58 | -12.25 | 19.62 | 3.02 | 12.61 | 19.42 | 24.67 | 3.37 | 8.50 |
| 8 | Herkenrath (1967) | 474 | 68.02 | 88.39 | 14.34 | 37.50 | 8.59 | 25.19 | -12.32 | 29.27 | -7.39 | 26.21 | 29.28 | 48.53 | 5.25 | 13.25 |
| 9 | Konkov&Zuperman (1967) | 6 | 21.91 | 22.66 | 18.36 | 19.03 | -2.26 | 6.25 | -21.42 | 21.72 | -2.16 | 4.05 | 16.00 | 16.43 | -4.65 | 6.55 |
| 10 | Bailey (1972a) | 19 | 66.80 | 71.39 | 16.72 | 23.17 | 8.84 | 12.49 | -18.68 | 20.39 | -9.22 | 13.43 | 15.77 | 20.43 | 0.67 | 4.68 |
| 11 | Bailey (1972b) | 0 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 12 | Subbotin (1973)-set1 | 7817 | 88.72 | 103.77 | 42.56 | 53.03 | 11.37 | 30.32 | -4.28 | 22.43 | 9.94 | 24.55 | 12.31 | 28.62 | -7.12 | 17.65 |
| 13 | Subbotin (1973)-set2 | 3961 | 74.53 | 90.94 | 50.17 | 60.24 | 10.95 | 30.93 | -2.66 | 16.25 | 20.38 | 30.62 | 18.19 | 27.09 | -9.49 | 19.84 |
| 14 | Subbotin (1973)-set3 | 1117 | 54.17 | 77.95 | 24.42 | 41.06 | -9.00 | 27.31 | -7.11 | 21.43 | 2.52 | 24.59 | 12.21 | 33.70 | -23.48 | 29.28 |
| 15 | Subbotin (1973)-set4 | 1876 | 98.44 | 116.38 | 70.92 | 83.04 | 24.80 | 46.34 | 12.48 | 29.47 | 36.80 | 47.77 | 30.86 | 44.69 | 2.44 | 21.10 |
| 16 | Subbotin (1973)-set5 | 2524 | 38.81 | 52.30 | 9.82 | 27.65 | 3.23 | 19.83 | -14.11 | 26.12 | -3.10 | 22.31 | 19.68 | 36.99 | 3.99 | 12.28 |
| 17 | Subbotin (1973)-set6 | 6899 | 98.41 | 113.91 | 60.74 | 72.34 | 24.61 | 40.72 | 6.88 | 27.22 | 18.41 | 30.80 | 18.32 | 34.52 | 8.12 | 25.20 |
| 18 | Subbotin (1973)-set7 | 0 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 19 | Janssen&Kervinen (1975) | 868 | -17.91 | 48.56 | -13.42 | 46.98 | -50.64 | 59.37 | -53.06 | 57.43 | -27.50 | 43.26 | -35.62 | 43.70 | -33.36 | 41.73 |
| 20 | Bailey (1977) | 352 | 6.91 | 15.42 | 13.18 | 19.10 | -37.13 | 39.72 | -29.35 | 30.26 | -4.33 | 12.31 | -13.77 | 17.52 | -19.15 | 24.52 |
| 21 | Nijhawan (1980) | 902 | -100.58 | 102.01 | 3.77 | 34.34 | -65.03 | 65.80 | -60.23 | 66.18 | -3.85 | 22.32 | -34.06 | 37.04 | -24.79 | 39.76 |
| 22 | Barzoni (1980) | 579 | 13.95 | 25.15 | 26.76 | 32.02 | -22.62 | 29.41 | -29.76 | 30.93 | 5.77 | 14.79 | -11.45 | 15.37 | 2.33 | 16.10 |
| 23 | Fung (1981) | 432 | -130.06 | 131.07 | -51.95 | 58.56 | -79.66 | 80.39 | -86.86 | 86.92 | -15.76 | 38.44 | -46.69 | 52.99 | -5.06 | 14.99 |
| 24 | Stewart (1981) | 472 | -52.20 | 61.17 | -14.00 | 52.21 | -61.38 | 65.09 | -46.56 | 55.02 | 0.62 | 36.91 | -37.46 | 45.02 | -13.40 | 20.24 |
| 25 | Kastner (1981) | 100 | 1.67 | 39.01 | 67.56 | 78.98 | 21.25 | 42.33 | 12.21 | 23.23 | 45.03 | 57.23 | 34.76 | 45.66 | 2.24 | 22.96 |
| 26 | Becker (1983) | 5441 | 43.63 | 64.12 | 21.16 | 37.89 | 11.49 | 24.21 | -11.56 | 24.00 | 0.57 | 24.08 | 11.49 | 28.05 | -2.67 | 9.45 |
| 27 | Borodin (1983) | 273 | 2.07 | 22.36 | 9.51 | 22.26 | -3.65 | 14.23 | -13.81 | 18.15 | -2.51 | 16.28 | 7.41 | 18.52 | -3.91 | 8.16 |
| 28 | Laperriere (1983) | 1538 | 26.06 | 33.63 | 36.31 | 42.53 | 8.32 | 25.29 | 6.88 | 23.46 | 129.28 | 169.01 | 31.88 | 41.90 | -6.47 | 13.92 |
| 29 | Annunziato (1983) | 0 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 30 | Liu (1984) | 33 | 0.34 | 60.12 | 73.78 | 76.44 | -53.61 | 53.85 | -11.25 | 13.28 | 48.66 | 51.22 | 25.35 | 27.73 | -0.06 | 9.14 |
| 31 | Gottula (1985) | 1248 | -38.57 | 52.59 | 197.53 | 226.51 | -36.63 | 40.75 | -29.76 | 36.16 | 122.64 | 147.07 | 6.37 | 43.93 | 59.69 | 95.15 |
| 32 | Babcock&Wilcox (1985) | 878 | 18.81 | 32.63 | 12.39 | 21.65 | -20.39 | 29.74 | -32.74 | 35.07 | -6.58 | 15.90 | -14.86 | 21.31 | -25.81 | 30.32 |
| 33 | Kohler&Hein (1986) | 684 | 69.64 | 85.95 | 50.40 | 61.21 | 34.51 | 44.66 | 5.41 | 21.44 | 23.61 | 34.16 | 31.81 | 41.53 | 10.68 | 21.74 |
| 34 | Swinnerton (1988) | 382 | -99.91 | 101.87 | -34.91 | 46.37 | -73.47 | 74.41 | -75.51 | 78.40 | -5.22 | 32.30 | -38.64 | 44.76 | -7.46 | 24.41 |
| 35 | Chen (1988) | 63 | -126.70 | 129.50 | -39.21 | 57.54 | -76.75 | 78.03 | -81.51 | 84.49 | -4.48 | 50.05 | -39.51 | 52.42 | -10.04 | 23.61 |
| 36 | Li (1988) | 397 | -49.53 | 73.00 | 40.91 | 67.07 | -41.12 | 45.83 | -19.27 | 29.41 | 17.31 | 46.30 | -14.02 | 30.30 | -27.26 | 39.54 |
| 37 | Chen (1989) | 243 | -57.53 | 64.81 | -4.27 | 49.28 | -53.88 | 58.03 | -37.25 | 46.25 | 21.60 | 40.24 | -27.98 | 38.25 | -6.17 | 19.36 |
| 38 | Mosaad&Johannsen (1989) | 0 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 39 | Chen (1994) | 325 | -21.78 | 109.94 | 42.57 | 106.94 | -32.76 | 57.69 | -18.48 | 58.27 | 24.39 | 72.46 | -6.22 | 52.92 | -3.34 | 66.51 |
| 40 | Leung (1994) | 2003 | -13.42 | 24.55 | -5.95 | 20.15 | -17.60 | 22.71 | -16.23 | 23.46 | -14.27 | 21.32 | -6.35 | 21.48 | -1.22 | 13.59 |
| 41 | Chen&Chen (1996) | 2307 | -71.48 | 108.80 | 48.34 | 97.06 | -40.96 | 50.96 | -15.70 | 42.80 | 53.97 | 79.54 | -1.04 | 42.07 | 8.54 | 42.29 |
| 42 | Doerffer (1997) | 0 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | **Overall** | **46068** | **41.77** | **86.86** | **37.57** | **66.79** | **-0.47** | **36.98** | **-10.66** | **31.33** | **16.95** | **51.12** | **8.78** | **33.59** | **-1.96** | **27.54** |

Table 4: Assessment of prediction errors of various prediction methods by sub-regions using the complete film-boiling database.

| | $0.0 < \alpha < 0.8$ | | $0.8 < \alpha < 1.0$ | | $x > 1.0$ | | $0.0 < \alpha < 0.8$ | | $0.8 < \alpha < 1.0$ | | $x > 1.0$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P = 100 - 1000 kPa; G = 0 - 300 kg /$m^2$ s | | | | | | P = 100 - 1000 kPa; G = 300 - 1000 kg /$m^2$ s | | | | | |
| | No. of datasets (No. of data points) | | | | | | No. of datasets (No. of data points) | | | | | |
| | 1 (3) | | 11 (4556) | | 5 (174) | | 2 (12) | | 5 (261) | | 0 (0) | |
| | Avg. err. | RMS err. | Avg. err. | RMS err. | Avg. err. | RMS err. | Avg. err. | RMS err. | Avg. err. | RMS err. | Avg. err. | RMS err. |
| Miropolkiy | -96.79 | 96.79 | -90.25 | 102.35 | 3.80 | 57.19 | -99.41 | 99.41 | -86.88 | 96.65 | - | - |
| Dougall-Rohsenow | -84.11 | 84.17 | 63.14 | 132.17 | 24.83 | 77.04 | -70.69 | 71.00 | 1.42 | 54.22 | - | - |
| Groeneveld-Delorme | -93.01 | 93.02 | -53.37 | 57.75 | -51.77 | 58.49 | -86.73 | 86.80 | -42.97 | 61.29 | - | - |
| Köhler-Hein | -94.02 | 94.02 | -43.12 | 55.16 | -42.38 | 50.85 | -79.56 | 80.41 | -23.46 | 37.63 | - | - |
| Chen-Chen | -62.69 | 63.01 | 45.43 | 91.02 | 3.72 | 58.25 | -28.31 | 32.29 | 36.38 | 47.11 | - | - |
| Shah-Seddiqui | -79.50 | 79.61 | -14.66 | 42.02 | -22.74 | 42.80 | -65.06 | 65.40 | -14.25 | 40.17 | - | - |
| Look-up Table | 2.24 | 4.13 | 7.04 | 58.61 | -22.44 | 39.96 | -1.72 | 5.68 | -8.98 | 18.17 | - | - |
| | P = 100 - 1000 kPa; G = 1000 - 3000 kg /$m^2$ s | | | | | | P = 100 - 1000 kPa; G = 3000 - 7000 kg /$m^2$ s | | | | | |
| | No. of datasets (No. of data points) | | | | | | No. of datasets (No. of data points) | | | | | |
| | 0 (0) | | 0 (0) | | 0 (0) | | 0 (0) | | 0 (0) | | 0 (0) | |
| | Avg. err. | RMS err. | Avg. err. | RMS err. | Avg. err. | RMS err. | Avg. err. | RMS err. | Avg. err. | RMS err. | Avg. err. | RMS err. |
| Miropolkiy | - | - | - | - | - | - | - | - | - | - | - | - |
| Dougall-Rohsenow | - | - | - | - | - | - | - | - | - | - | - | - |
| Groeneveld-Delorme | - | - | - | - | - | - | - | - | - | - | - | - |
| Köhler-Hein | - | - | - | - | - | - | - | - | - | - | - | - |
| Chen-Chen | - | - | - | - | - | - | - | - | - | - | - | - |
| Shah-Seddiqui | - | - | - | - | - | - | - | - | - | - | - | - |
| Look-up Table | - | - | - | - | - | - | - | - | - | - | - | - |
| | P = 1000 - 6000 kPa; G = 0 - 300 kg /$m^2$ s | | | | | | P = 1000 - 6000 kPa; G = 300 - 1000 kg /$m^2$ s | | | | | |
| | No. of datasets (No. of data points) | | | | | | No. of datasets (No. of data points) | | | | | |
| | 4 (47) | | 8 (877) | | 5 (727) | | 4 (206) | | 11 (1094) | | 9 (367) | |
| | Avg. err. | RMS err. | Avg. err. | RMS err. | Avg. err. | RMS err. | Avg. err. | RMS err. | Avg. err. | RMS err. | Avg. err. | RMS err. |
| Miropolkiy | -84.44 | 84.69 | -37.65 | 69.49 | -9.11 | 30.73 | -65.55 | 67.82 | 11.67 | 68.57 | 19.84 | 44.21 |
| Dougall-Rohsenow | -70.00 | 70.32 | 19.56 | 79.65 | -0.07 | 33.22 | -43.09 | 47.88 | 54.64 | 94.49 | 27.14 | 48.40 |
| Groeneveld-Delorme | -86.21 | 86.27 | -47.55 | 56.11 | -49.67 | 52.95 | -70.91 | 71.87 | -16.42 | 39.33 | -9.08 | 30.56 |
| Köhler-Hein | -83.75 | 84.13 | -29.68 | 50.34 | -44.41 | 47.52 | -58.51 | 60.92 | -1.70 | 38.92 | -24.85 | 35.26 |
| Chen-Chen | -41.78 | 42.60 | 19.34 | 58.11 | -15.51 | 30.97 | 7.72 | 28.48 | 47.32 | 68.52 | 6.98 | 29.84 |
| Shah-Seddiqui | -66.64 | 66.91 | -19.11 | 41.34 | -25.98 | 33.14 | -49.52 | 51.36 | 8.85 | 39.71 | -4.14 | 21.10 |
| Look-up Table | -10.51 | 16.36 | -6.42 | 41.70 | -22.46 | 34.46 | 5.13 | 13.93 | 17.76 | 45.97 | 0.22 | 25.63 |
| | P = 1000 - 6000 kPa; G = 1000 - 3000 kg /$m^2$ s | | | | | | P = 1000 - 6000 kPa; G = 3000 - 7000 kg /$m^2$ s | | | | | |
| | No. of datasets (No. of data points) | | | | | | No. of datasets (No. of data points) | | | | | |
| | 2 (10) | | 6 (449) | | 3 (12) | | 0 (0) | | 2 (91) | | 0 (0) | |
| | Avg. err. | RMS err. | Avg. err. | RMS err. | Avg. err. | RMS err. | Avg. err. | RMS err. | Avg. err. | RMS err. | Avg. err. | RMS err. |
| Miropolkiy | -74.08 | 74.24 | -11.16 | 26.87 | 65.11 | 67.59 | - | - | -25.54 | 28.45 | - | - |
| Dougall-Rohsenow | -36.04 | 37.83 | 27.89 | 34.74 | 69.12 | 70.79 | - | - | 0.60 | 15.02 | - | - |
| Groeneveld-Delorme | -64.66 | 65.10 | 3.35 | 20.02 | 58.31 | 60.28 | - | - | -13.30 | 19.47 | - | - |
| Köhler-Hein | -45.28 | 46.63 | -10.97 | 14.04 | 3.84 | 15.08 | - | - | -13.63 | 19.66 | - | - |
| Chen-Chen | 42.11 | 45.78 | 14.76 | 23.21 | 41.31 | 43.28 | - | - | -9.03 | 15.84 | - | - |
| Shah-Seddiqui | -45.17 | 45.68 | 4.43 | 15.33 | 32.68 | 50.96 | - | - | 0.73 | 16.33 | - | - |
| Look-up Table | 1.75 | 4.50 | 0.16 | 8.32 | 10.13 | 13.04 | - | - | 0.70 | 8.44 | - | - |

| | $0.0 < \alpha < 0.8$ | | $0.8 < \alpha < 1.0$ | | $x > 1.0$ | | $0.0 < \alpha < 0.8$ | | $0.8 < \alpha < 1.0$ | | $x > 1.0$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P = 6000 - 15000 kPa; G = 0 - 300 kg /m² s | | | | | | P = 6000 - 15000 kPa; G = 300 - 1000 kg /m² s | | | | | |
| | No. of datasets (No. of data points) | | | | | | No. of datasets (No. of data points) | | | | | |
| | 1 (14) | | 5 (72) | | 4 (526) | | 2 (189) | | 16 (11732) | | 12 (2875) | |
| | Avg. err. | RMS err. | Avg. err. | RMS err. | Avg. err. | RMS err. | Avg. err. | RMS err. | Avg. err. | RMS err. | Avg. err. | RMS err. |
| Miropolkiy | -70.71 | 70.87 | 10.14 | 45.45 | 0.89 | 46.21 | 13.75 | 25.21 | 77.85 | 94.91 | 94.64 | 118.15 |
| Dougall-Rohsenow | -65.50 | 65.74 | 11.90 | 44.56 | 2.80 | 46.13 | 19.29 | 26.98 | 53.06 | 65.29 | 70.46 | 82.47 |
| Groeneveld-Delorme | -83.80 | 83.87 | -47.42 | 51.14 | -50.00 | 53.84 | -17.57 | 23.63 | 11.72 | 35.20 | 28.29 | 47.00 |
| Köhler-Hein | -82.14 | 82.29 | -41.89 | 46.07 | -47.35 | 51.43 | -14.41 | 21.24 | -0.42 | 20.17 | 7.57 | 35.96 |
| Chen-Chen | -53.02 | 54.06 | -14.45 | 31.13 | -15.52 | 36.19 | 68.06 | 78.77 | 20.84 | 32.55 | 34.54 | 44.68 |
| Shah-Siddiqui | -68.10 | 68.23 | -39.27 | 43.11 | -29.31 | 37.87 | 8.76 | 25.68 | 22.41 | 34.62 | 12.49 | 24.99 |
| Look-up Table | -28.04 | 29.72 | -22.86 | 30.59 | -23.46 | 38.40 | -8.54 | 15.22 | -6.97 | 23.41 | 9.52 | 25.66 |
| | P = 6000 - 15000 kPa; G = 1000 - 3000 kg /m² s | | | | | | P = 6000 - 15000 kPa; G = 3000 - 7000 kg /m² s | | | | | |
| | No. of datasets (No. of data points) | | | | | | No. of datasets (No. of data points) | | | | | |
| | 6 (1581) | | 15 (4115) | | 6 (216) | | 5 (244) | | 5 (2189) | | 0 (0) | |
| | Avg. err. | RMS err. | Avg. err. | RMS err. | Avg. err. | RMS err. | Avg. err. | RMS err. | Avg. err. | RMS err. | Avg. err. | RMS err. |
| Miropolkiy | 24.90 | 32.48 | 31.76 | 43.90 | 22.29 | 43.49 | 28.33 | 43.56 | -13.39 | 20.97 | - | - |
| Dougall-Rohsenow | 24.12 | 31.29 | 25.41 | 34.32 | 11.35 | 30.23 | 31.31 | 50.36 | -6.48 | 16.98 | - | - |
| Groeneveld-Delorme | 8.19 | 21.19 | 8.28 | 21.88 | 3.14 | 24.53 | 24.98 | 42.31 | -14.37 | 19.51 | - | - |
| Köhler-Hein | -0.08 | 18.61 | -7.68 | 17.97 | -15.73 | 28.69 | 13.91 | 40.34 | -16.19 | 22.08 | - | - |
| Chen-Chen | 85.89 | 129.66 | 7.25 | 20.26 | -7.17 | 23.49 | 175.83 | 255.64 | -14.39 | 20.19 | - | - |
| Shah-Siddiqui | 25.69 | 34.79 | 20.09 | 31.54 | -4.72 | 23.21 | 37.12 | 56.95 | -5.01 | 18.47 | - | - |
| Look-up Table | -3.86 | 14.18 | -2.12 | 14.23 | 2.43 | 14.57 | -2.20 | 12.59 | -0.78 | 8.96 | - | - |
| | P = 15000 - 20000 kPa; G = 0 - 300 kg /m² s | | | | | | P = 15000 - 20000 kPa; G = 300 - 1000 kg /m² s | | | | | |
| | No. of datasets (No. of data points) | | | | | | No. of datasets (No. of data points) | | | | | |
| | 0 (0) | | 0 (0) | | 0 (0) | | 7 (563) | | 8 (5798) | | 6 (2830) | |
| | Avg. err. | RMS err. | Avg. err. | RMS err. | Avg. err. | RMS err. | Avg. err. | RMS err. | Avg. err. | RMS err. | Avg. err. | RMS err. |
| Miropolkiy | - | - | - | - | - | - | 72.28 | 88.56 | 106.41 | 116.18 | 82.53 | 100.73 |
| Dougall-Rohsenow | - | - | - | - | - | - | 12.39 | 30.04 | 43.79 | 51.91 | 41.24 | 51.68 |
| Groeneveld-Delorme | - | - | - | - | - | - | -5.81 | 24.47 | 16.25 | 31.21 | 21.74 | 31.76 |
| Köhler-Hein | - | - | - | - | - | - | -20.61 | 31.62 | -7.73 | 22.04 | 15.87 | 26.06 |
| Chen-Chen | - | - | - | - | - | - | -11.16 | 22.54 | 4.86 | 18.57 | 7.16 | 19.28 |
| Shah-Siddiqui | - | - | - | - | - | - | 21.11 | 48.01 | 12.74 | 30.26 | -3.08 | 22.99 |
| Look-up Table | - | - | - | - | - | - | -14.82 | 23.65 | -5.91 | 17.64 | 2.90 | 14.73 |
| | P = 15000 - 20000 kPa; G = 1000 - 3000 kg /m² s | | | | | | P = 15000 - 20000 kPa; G = 3000 - 7000 kg /m² s | | | | | |
| | No. of datasets (No. of data points) | | | | | | No. of datasets (No. of data points) | | | | | |
| | 8 (2097) | | 8 (1627) | | 3 (281) | | 3 (168) | | 3 (65) | | 0 (0) | |
| | Avg. err. | RMS err. | Avg. err. | RMS err. | Avg. err. | RMS err. | Avg. err. | RMS err. | Avg. err. | RMS err. | Avg. err. | RMS err. |
| Miropolkiy | 41.46 | 54.85 | 50.62 | 67.55 | 4.37 | 25.75 | 7.55 | 14.80 | -8.03 | 14.31 | - | - |
| Dougall-Rohsenow | 0.99 | 24.02 | 8.61 | 31.86 | -17.68 | 23.02 | -21.33 | 23.47 | -30.12 | 31.20 | - | - |
| Groeneveld-Delorme | -0.90 | 18.32 | 5.07 | 23.71 | -6.07 | 22.19 | -13.26 | 15.54 | -22.28 | 23.18 | - | - |
| Köhler-Hein | -22.73 | 30.38 | -19.28 | 31.84 | -22.90 | 26.62 | -37.47 | 39.19 | -42.93 | 43.88 | - | - |
| Chen-Chen | -13.07 | 23.99 | -14.08 | 27.76 | -30.15 | 32.12 | -30.37 | 32.11 | -41.07 | 41.52 | - | - |
| Shah-Siddiqui | 14.17 | 33.82 | 10.69 | 40.34 | -11.47 | 23.92 | -12.45 | 16.99 | -26.94 | 28.89 | - | - |
| Look-up Table | 2.34 | 9.88 | 1.31 | 12.66 | -0.26 | 12.43 | -1.40 | 8.22 | -5.80 | 11.23 | - | - |

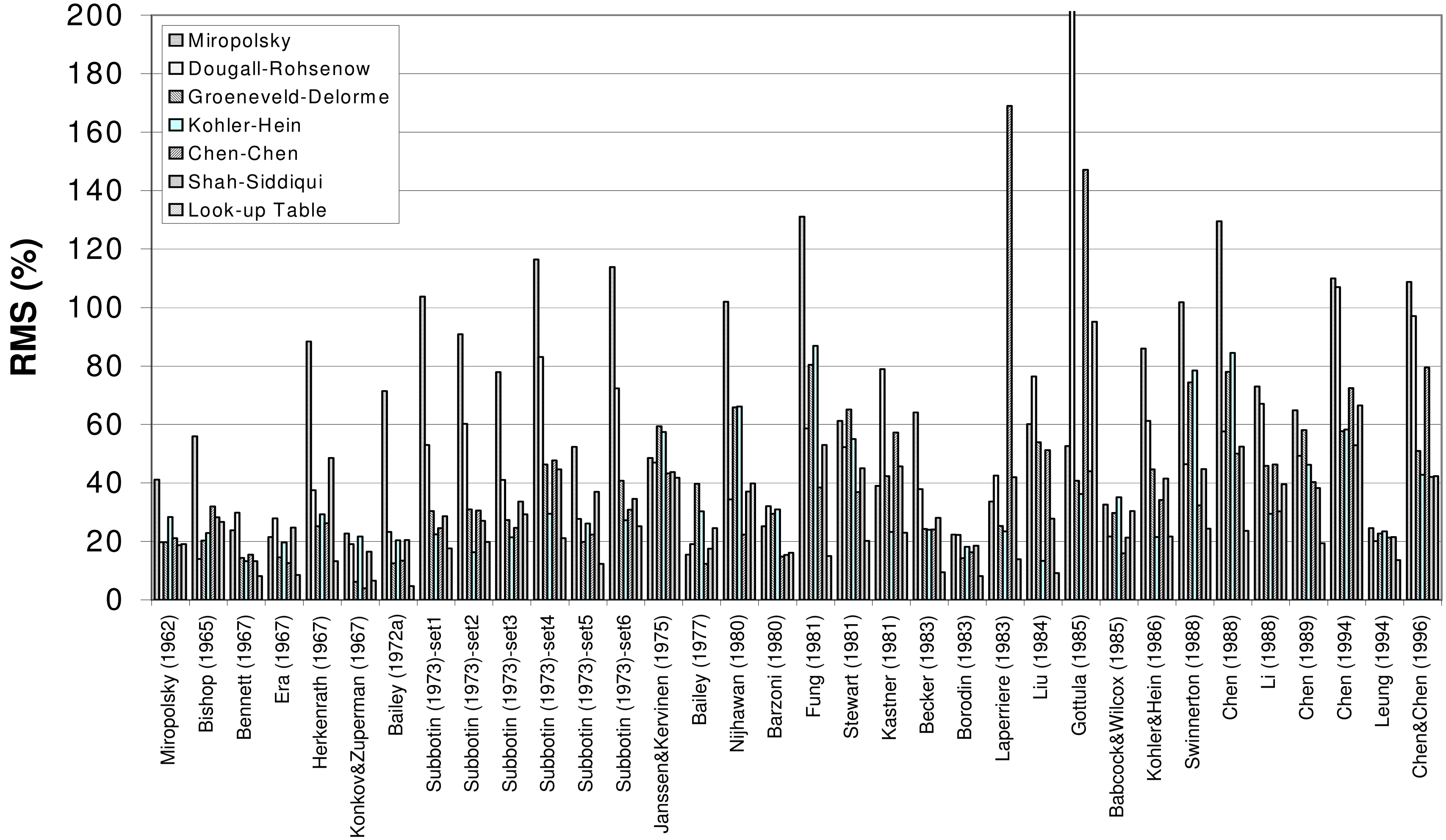


Figure 2: Error Distributions of Model Predictions Versus Datasets

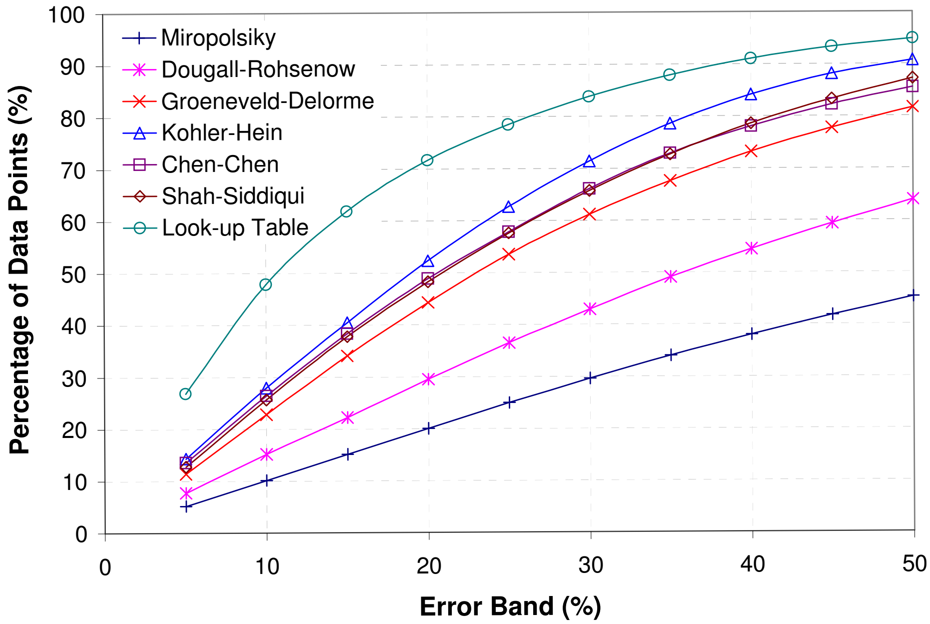


Figure 3: Percentage of data points predicted within a given error band for the combined database.

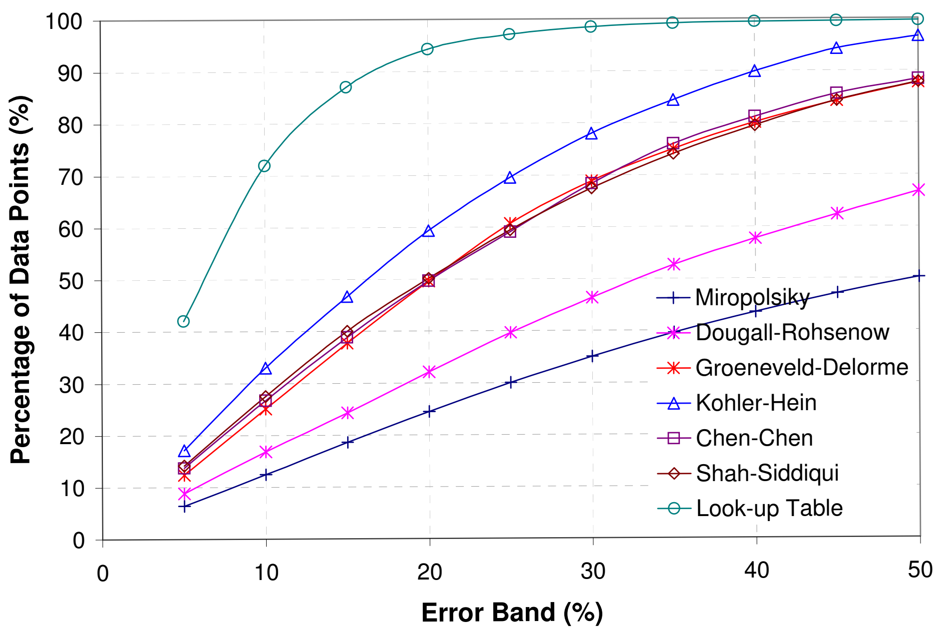


Figure 4: Percentage of data points predicted within a given error band for the fully developed database.