# In Memoriam Prof. Piet Bennema (1932-2016)

Piet Bennema, one of the founders of crystal growth science in The Netherlands, passed away on 25 June 2016. He was born in Tarutung (Dutch East Indies, now Indonesia) on 15 December 1932. After being interned for three years in a Japanese camp during World War II, he was repatriated to the Netherlands, where he finished secondary school successfully despite the difficult circumstances during that period. He then left for the Free University in Amsterdam to study physical chemistry, in which he specialized in crystallography. As a student he also spent a short period with P. Hartman and W.G. Perdok at the University of Groningen, and thus got acquainted with the then newly developed Periodic Bond Chain theory for crystal morphology.

*Prof. Piet Bennema during a thesis defense ceremony in 2003.*

In 1959 he obtained his master's degree and started his PhD study on the crystal growth of potash alum and sodium chlorate crystals from aqueous solutions at extremely low supersaturation. The results were interpreted using a modified version of the, at that time little known, Burton-Cabrera-Frank theory [1]. From his measurements and theoretical analysis he concluded that these crystals grow via a spiral mechanism and this work was very well received in the scientific world. He received his PhD in 1965 under the supervision of W.G. Burgers and van H.G. van Bueren. After a period as a post-doc at the University of Groningen and as an assistant professor in Chapel Hill (North Carolina, U.S.A.), he became Reader at Delft University of Technology in 1969. There he continued his crystal growth experiments, and, together with the theoretical physicist G.H. Gilmer (on sabbatical leave from Washington and Lee University, Virginia, U.S.A.) he performed the first computer simulations of crystal growth processes [2]. This and subsequent computer studies had a tremendous impact on the theoretical research of crystal growth in his own lab and elsewhere.
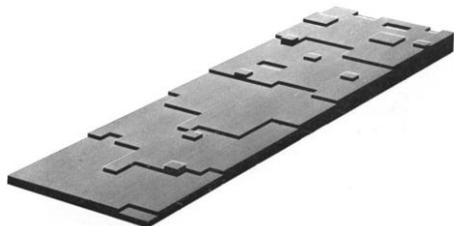
*A step train from an early computer simulation of crystal growth (from. C. van Leeuwen, R. van Rosmalen and P. Bennema, Surf. Sci. 44 (1974) 213).*

After eight years at Delft University of Technology, Piet was appointed as a full Professor at the University of Nijmegen in 1976 where he would stay for the rest of his long career. There he deepened the theoretical concepts of crystal growth, together with the theoretician J. van der Eerden. This led to a better insight into the concepts of bond strength, supersaturation, step energy, two-dimensional nucleation, kinetic roughening and spiral growth in crystallization. In cooperation with I. Sunagawa and K. Tsukamoto (Tokohu University, Sendai, Japan) and, at that time PhD student and later his associate professor, W. van Enckevort, he became familiar with the ex-situ and in-situ observation of crystal surfaces using advanced optical microscopy and AFM [3]. This work supported his theoretical concepts, which were not obvious at all at that time. He also remained fascinated by the Hartman-Perdok theory; he further developed this approach for deducing crystal morphology from crystal structure to the more modern Connected Net theory [4-6]. Together with H. Knops (University of Nijmegen) he integrated this theory with modern statistical mechanics concepts and together with local staff member H. Meekes, he was able to tackle the habits of real crystal structures in detail using computer programs. He was also mesmerized by the morphology of
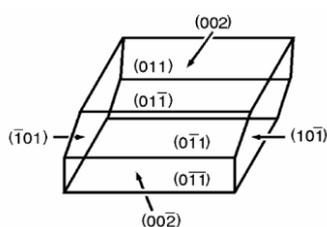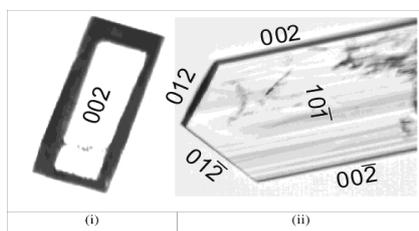
*Experimental and predicted growth morphologies of venlafaxine. From ref. [6].*

incommensurate crystals and collaborated on this topic with the well-known expert, A. Janner (University of Nijmegen) [7]. Of course, also "common" crystals, such as paraffin and other organic crystals, salts grown from aqueous solution, semiconductors and even fractals received his attention. Due to this, he kept in touch with many industries and collaborated on the more fundamental aspects of industrial crystallization with G. van Rosmalen's group at Delft University of Technology.

Piet was well known by everyone involved with crystal growth and travelled to many parts of the world, including countries behind the Iron Curtain. Of special importance was his first journey to Japan in 1975, which, despite his harsh war experiences, was the beginning of a warm hearted collaboration with the Japanese crystal growth community. His reputation was established by the conferment of the Frank Award in 1995 by the International Organization for Crystal Growth. In 1998 Piet retired, but during the years after he still continued crystal growth research and regularly visited his former group of Solid State Chemistry. In his final years his health was gradually failing and he was forced to stop scientific activities.

Piet Bennema was a unique personality with a lot of interests. For instance, he was a skilled painter and produced many pictures as well as etches of towns and landscapes inspired by his journeys. He also wrote a book about his stay as a child in the Japanese internment camp. In addition he was very interested in theology and philosophy and was involved in many discussions in his group. Piet was always an enthusiastic, persevering researcher, tackling many difficult problems and never giving up. He could get along very well with everyone, including colleagues, his more than 30 PhD students and the manifold of graduate and undergraduate students. Piet was an enjoyable companion in our group and at the many conferences he visited. He was a passionate promoter of crystal growth science and can be considered as one of the founders of modern crystal growth science in the Netherlands and beyond. We will remember him fondly and with respect.



*An oil painting of a USA landscape with the Rocky Mountains made by Piet Bennema*

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[1]    P. Bennema and H.B. Klein Haneveld, *Error analysis of a technique to determine the rate of crystal growth from solution at low supersaturations & A least square method to determine a theoretical rate of growth versus relative supersaturation curve from accurate data,* J. Cryst. Growth **1** (1967) 225 and 232.

[2]    G. H. Gilmer and P. Bennema, *Simulation of crystal growth with surface diffusion*, J. Appl. Phys. **43** (1972) 1347.

[3]    I. Sunagawa, and P. Bennema, *Morphology of growth spirals, theoretical and experimental.* In: W.A. Wilcox (Editor), Preparation and Properties of Solid State Materials, Vol 7, Marcel Dekker, New York, (1982) pp. 1 -129.

[4]    P. Bennema, *Growth and morphology of crystals* In: Handbook of Crystal Growth, Vol.1a, ed. by T.J. Hurle (Elsevier Science Publishers, Amsterdam 1993) p. 477-581

[5]    P. Hartman and P. Bennema, *The attachment energy as a habit controlling factor: Theoretical considerations*, J. Cryst. Growth **49** (1980) 145.

[6]    P. Bennema, H. Meekes, S. X. M. Boerrigter, H. M. Cuppen, M.A. Deij, J. van Eupen, P. Verwer and E. Vlieg, *Crystal growth and morphology: new developments in an integrated Hartman-Perdok-connected net-roughening transition theory, supported by computer simulations*, Cryst. Growth Des., **4** (2004), 905.

[7]    B. Dam, A. Janner, P. Bennema, W.H. van der Linden and T. Rasing, *Observation of bands of faces on incommensurate $Rb_2ZnBr_4$ single crystals*, Phys. Rev. Lett. 50 (1983) 849.