INTRODUCTION

In all technical fibre flows known to the author, the fibres are transported by flow in transient flocs (i.e. groups of fibres) rather than one by one. The reason for this can only be understood in the context of historic development. In Part 1 of this historic investigation the roots of fibre flow research are traced to the beginning of the 19th century. The subsequent development is followed through its formative period in the first half of the 20th century up to about WW2. Part 2 will continue up to about 1960s when the present main tradition had been well established. In Part 2, an example of an alternative approach will also be given, and some proposals for future development presented.

The ambition in this work is to present this development as well as the cultural and social soil from which it sprung. Although the goal of natural science is – and should be – results that are independent of personal and social factors, it is the author's firm belief that they play an important role, as will be exemplified many times in this work. E.g. the great and creative scientists set the frames by creating the metaphors we other play with. Some of them have also more directly also influenced the development of fibre...
flow research – if favourably or not will be discussed. The literature on theoretical fibre flow gives an impression of naturalness. The author will do his best, with the assistance of some of these great scientists, to dispel these impressions in order to stimulate to a more open-minded approach of the theory of technical fibre flows. The following research history is thus presented with the intention to open the eyes of the researchers now active in this field, with the hope that alternative methods and ideas can be exploited.

It is not possible to write a chronological history for such a composed development. Instead, a number of traditions has been distilled. The focus will shift from one to another roughly as they enter into the development. These traditions are, of course, somewhat arbitrary and idealised, and interaction between them has been normal, as often researchers have been active in more than one tradition. The scheme in the Appendix may here help to see this and also to catch the entirety.

The description will focus on the formative period, before the main development had been cemented and alternative paths for development were still available. This means up to about the 1960s. The subsequent development will just be sketched, since it is accessible through the scientific literature. This work has for length reasons been divided in two parts. Part 1 roughly covers the period before WW2, including its sequel. Part 2 covers the rest and presents an alternative approach. Finally, some suggestions for future work are given.

2 THE TECHNICAL TRADITION

The important Hagen-Poiseuille equation was developed by the German hydraulic engineer Gotthilf Hagen and the French physiologist Jean Louis Poiseuille between about 1840 and 1860. The pressure drops in tubes could then be calculated if the material property viscosity was known or could be measured, e.g. using the same equation and a capillary viscometer. Before the centrifugal pump was developed in the second half of the 19th century, paper pulps (suspensions of wood fibre) were pumped with various types of displacement pumps such as plunger pumps. Knowledge of the flow properties was not then absolutely necessary. It was more a matter of using enough large pipes, pumps and motors to deliver a sufficient amount of pulp, then named stuff or stock. With the gradual introduction of centrifugal pumps in the pulp and paper industries, the flow properties of the stuff also became a matter of importance. Trimbe is reported [1] in 1907 to have been the first to measure the pressure drop in tubes (then riveted) at different fibre concentrations and flow rates.

The first theoretical attempts naturally followed Hagen-Poiseuille’s hydrodynamic path, e.g. Pfarr [2] in 1907 and Haussner [3] in 1908. These early researchers, however, had already observed that the stuff did not behave like ordinary fluids. Practical needs were met with leaflets and brochures from pump manufacturers like Allis-Chalmers, see e.g. Baldwin and van den Akker [4] in 1939. But even when more general design methods were sought, it was not then self-evident (and is not even today [5]) that a material flow property could be assigned to these fibre suspensions. It was still some decades before Eugene Bingham had established rheology as a separate scientific discipline in 1931, which began the systematization of rheological concepts as we know them today.

The reason for the strange pipe pressure drop curves for the stock was quite well under-
stood already in the 1920’s, viz. that the entire pipe cross section was not sheared but that a central fibre plug remained. For example, see Figure 1a from Forrest and Grierson [6]. In particular, it was observed, without giving the effect a special name, that at higher flow rates the pulp suspensions experienced lower pressure drops than for the suspending medium (normally water) at same volumetric flow rates as observed in Figure 1b. When the same effect was found in polymer solutions after WW2 it was named “turbulence damping”, and this designation was later used also for fibre flows. The results of a more thorough and systematic pipe flow investigation for different paper pulps were published in the mid-1930s by Brecht and Heller [7, 8]. For example, velocity profiles were measured with Pitot tubes. Their investigations largely confirmed what was known earlier (Brecht is Berthold Brecht’s younger brother Walter, professor in Paper Technology in Darmstadt. He was more papermaker than scientist, his name here serving more as a department stamp. Heller was Norwegian who made his doctoral work at the paper machine manufacturer Voiht in Heidenheim to complete his Dr.-Ing. degree at Darmstadt. Norway at that time had not yet established its first technical university.)

The first researcher with a more profound understanding of the nature of pulp, however, appears to have been the Dane Sigurd Smith, later head of the laboratories of De Forenede Papirfabrikker A/S. In his thesis work “Heltøjshollænderen” [9] he investigated fibre milling as well as the recirculating channel flow in Hollander (Figure 2), named so since first used there in the 17th century, then driven by windmills. In such machines the pulp suspension is repeatedly returned to the tackle under the cylinder where the actual milling takes place. The milling consists of cutting and crunching fibres between themselves and steel bars to make them shorter and/or more flexible, a treatment which directly influences the paper quality. In the gravity-driven open channel return flow, Sigurd Smith set off in an almost Leonardian way to demonstrate plug flow (a straight line painted on top of the stuff remained straight and sticks pushed vertically through the stuff remained vertical) and yield stress (a stationary sloping surface kept its slope and an 11 lb. spanner on top of the stuff did not sink). He also observed network ruptures (named cleavages), although he presented no rule for their orientation or proposed any mechanism behind their formation. Smith even measured the frictional force in such ruptures with wooden “boats”. In picturesque, but appropriate terms he described this flow as “the valleyward movement of a glacier under the pressure of the upper masses of ice”. He also discussed the plug flow form in energetic terms as being caused by a lower friction between the wall and pulp suspension than within the suspension itself.

Smith’s thesis was regarded as sufficiently important by the pulp and paper branch to pay for its translation to English [10]. Nevertheless, its influence on academic research described in the present work was nil. It must, however, be admitted that the pulp flow passage in Smith’s work is not easy to find (it took the author about...
ten years before he knew about the book, and he still finds it difficult to find this passage at p. 149 in the translated version). Twenty years later Baldwin and van den Akker [4] followed up the fibre/fibre frictional aspects of Smith’s work.

3 THE PHYSICAL TRADITION

It may perhaps be difficult to understand today that atoms were not generally accepted even by leading scientists until the beginning of the 20th century. Chemists had used them as a practical tool since the late 18th century and physicists like Gassendi, Hooke and Newton were atomists. Some stalwarts, however, demanded more direct proof of its existence before accepting the atom as more than a useful working hypothesis. For example the great Scottish scientist Lord Kelvin of Larges, who died in 1907, was in later years against almost everything new. A biographer divided his career in two parts; a first when it was impossible for him to do anything wrong, and a second when it was impossible to get anything right. He was thus against atoms (vortices was better), he was against Maxwell’s equations (his own were better), he did not believe Darwin (God was better) and refused Frederick Lanchester’s 1897 manuscript on aerial flight, stating ”everyones knows that it is impossible to fly with a machine heavier than air”, and to make matters even worse the sun would soon be burnt out, etc. etc. Another opponent of atoms was the very influential physical chemist Wilhelm Ostwald, Nobel Prize winner in 1909 for catalysts, chemical equilibria and reaction kinetics [11] who favoured energy, like the philosopher and universal genius Ernst Mach (whose philosophy played a decisive role for Einstein in his development of the relativity theory). The archsceptic Ostwald’s (consequently also organised atheist) hard debates with the atomist Ludwig Boltzmann (with the ambition of becoming physic’s Darwin, his hero) are legendary, but both were stimulated and remained personal friends.

In 1906 Albert Einstein (Nobel Prize winner in 1921 for the photoelectric effect) published an article in Annalen der Physik entitled “Eine neue Bestimmung der Moleküldimensionen” [12] containing his thesis work. By solving the Navier-Stokes’ equation he found that the viscosity \( \mu \) of a dilute suspension of rigid spheres was given by

\[
\mu = \mu_0 (1 + c_v),
\]

where \( \mu_0 \) is the liquid viscosity and \( c_v \) the volume fraction of spheres.

Who does not want to share the glamour (if just a little) of one of the all-time greatest scientists? Thus, Einstein thrones at the beginning of most texts of suspension flow, although he himself does not seem to have been too engaged in fluid dynamics. As the title indicates, his primary interest instead was just to prove the existence of atoms. Most of his work during this period fits into this theme: the photoelectric effect, the Brownian motion [13], etc. In his thesis work he had applied a solution found in Gustaf Kirchhoff’s impressive textbook “Vorlesungen über mathematische Physik” [14] from 1877 (Both texts look strangely similar, which is perhaps not so strange since they were both printed at Teubner Verlag, probably using the same types). In his own hand Einstein, however, contributed with a mistake. Later Jacques Bancelin [15, 16] (at Perrin’s laboratory) found that this formula did not fit his own experimental results. Einstein was informed and had his calculations checked. The trivial miscalculation was found and the result changed \([17]\) to \( \mu = \mu_0 (1 + 5c_v/2) \), in better agreement with the experiments. In his experiments Bancelin had used micron-sized gamboge spheres painstakingly fractionated with a centrifugal technique developed at Sorbonne by the physical chemist Jean Perrin [18] (Nobel Prize winner in 1926 “for his work on the discontinuous structure of matter, and especially for his discovery of sedimentation equilibrium”). Perrin in 1908 had found that such spheres suspended in a liquid with a slightly lower density did not sink to the bottom due to bombardment by molecules, i.e. Brownian motion. The idea of using sedimentation equilibria to study Brownian motion originated from the Polish theoretical physicist Marian Smoluchowski. These systems therefore came into focus in the debate for and against the atoms existence [19, 20].

What was later named Brownian motion had already been observed for pollen grains in the microscope by the French botanist (palaeontology) Adolphe-Théodore Brongniart [21] and the English botanist Robert Brown [22] in the late 1820s. Brown in addition proved that the motion was not of biological origin, although the actual cause remained obscure. Thermal currents caused by the microscope illumination was proposed in 1867 by the Vienna professor Sigmund Exner (who studied comparative physiology, especially ordinary and facet eyes) as discussed
in [23]. It was not until the late 1880s until there was convincing proof by e.g. the Frenchman Leon Gouy [24], that Brownian motion was a property of matter itself. Thereafter, it more generally aroused the physicists’ interest. E.g. it was found that smaller particles moved faster than larger. Due to the motion’s jerkiness attempts to correlate its velocity were less successful, e.g. by Sigmund Exner’s son Felix [23] in 1900, also professor at the Vienna University. Albert Einstein then reinterpreted the results in terms of particle displacements (mean square) and developed his famous theory [13]. The same reformulation had been made earlier but not been published by Marian von Smoluchowski [25] in Krakow (born, raised and educated in Vienna, Joseph Stefan’s and Felix Exner’s student, 1896 – 97 in Glasgow at Kelvin’s laboratory, 1905 – 06 at Cavendish with J.J. Thompson; enthusiastic alpinist, who climbed 1909 the Matterhorn, 1911-12 president of the Tourist Section of the Polish Tatra Society, “Silber Edelweiss” from the German and Austrian Alpine Society, Figure 3). It was these theories that inspired Perrin to undertake microscope studies with fractionated gamboge spheres. The agreement with the atom-based theory was sufficiently good to convert even a sceptic like Wilhelm Ostwald to atomism. An early experimental attempt to verify the theory with the help of colloidal gold suspensions using Henry Siedentopf’s and Richard Zsigmondi’s ultra microscope had also been made in Uppsala by Theodor (The) Svedberg [26] in 1906 (Nobel Prize winner in 1926 for his colloidal investigations). Another pioneering experiment was Victor Henri’s cinematographic studies of the Brownian motion from 1908 [27].

4 THE COLLOIDAL TRADITION

With Svedberg we have definitely moved into the new and very active field of colloid science, the “nano” of that era. Svedberg studied colloidal gold systems [26, 28] (1906, 1912) with ultracentrifuges. Zsigmondy (Nobel Prize winner in 1925 for his colloidal investigations) used his ultramicroscope. A scientist of the previous generation who still took part in this debate was Svante Arrhenius (Boltzmann’s student and Nobel Prize winner in 1903 for his electrolytic theory). Already in 1887 he had been interested in the molecular mechanisms behind the viscosity of solutions [29] and had in 1915 extended his interest to the viscosity of colloids [30] such as sulphur, proteins, globulins, and egg albumin. His logarithmic correlation was better than Einstein’s over a wider concentration range, but had a more general scientific character than Einstein’s microhydrodynamics-based formula.

The mechanism behind the coagulation of colloidal systems was at that time not at all clear, and a theory was not forthcoming. Therefore, Zsigmondy encouraged Smoluchowski to help. Smoluchowski, with his Brownian motion background but also interests in microhydrodynamics [31, 32] identified Brownian motion as central. With this view, a solute molecule differs from a colloidal particle only in mass. He classified the suspended colloidal particles as singlets, doublets, triplets, ..., and applied Brownian motion theory that implied that singlets moved faster than doublets. He then used statistical arguments similar to those used by Maxwell and Boltzmann in their gas kinetic theories, and solved the problem. It is for this conceptual breakthrough [33, 34] in the understanding of the coagulation process that Smoluchowski mainly is remembered today, but he was a great scientist of a more general importance (Smoluchowski died already in 1917 of dysentery just 45 years old but would otherwise without doubt have received the Nobel Prize for his coagulation theory, since many of the less central contributors to the solution of this problem received it).

Smoluchowski’s theory gave the framework but mechanistic details remained to be filled in. In 1916 his theoretical and also experimental interest had also turned to the viscosity of colloids [35], e.g. using the results for protein solutions obtained by Wolfgang Joseph Pauli [36] in 1913 (A doctor of medicine who, under the influence of his friend Ernst Mach turned to science and became a biochemistry professor at the Insti-
tut für medizinische Kolloidchemie der Universität Wien. Father of the physicist Wolfgang Ernst Pauli, Nobelist 1945 for the exclusion principle, second name after his godfather Mach, in the scientific literature then naming himself Wolfgang Pauli Jr., Figure 4).

The advancements in colloid science did not remain unobserved in the pulp and paper industry. In 1932 Campbell and Yorsten [37] published a study of the reflocculation of very dilute fibre suspensions after a mesh. James Strachan [38] in 1935 discussed the effect on milling of “colloidally active material,” and John Wollwage [39] at Kimberly-Clark in 1939 presented a larger fibre flocculation investigation in laminar tube flow, also at non-technically dilute fibre conditions (0.01%). We will return to their contributions in Part 2 of this work.

5 THE FLUID DYNAMIC TRADITION

A first contribution to the coagulation mechanism, in a way, can be said to have been presented in 1922 when the mathematician George Barker Jeffery [40] in Cambridge extended Einstein's calculations to ellipsoids (Quaker, conscientious objector and therefore in prison a short time in 1916, later translator Einstein's work, and even later organiser of the educational system in West Africa, a human contrast to many of the fluid dynamicists figuring in this work boyscoutingly engaged in military projects and mass destructive weaponry). Jeffery was, however, disturbed about the fact that the ellipsoids according to his solution just moved on in the same closed orbits they had started in. This made the viscosity unrealistically dependent on the initial orientation distribution. Therefore, he suggested that the ellipsoids in practice drifted toward a position of least dissipation rate, referring to a theorem of von Helmholtz and Korteweg that, however, applied only for stationary conditions. Just one more work of Jeffery's hand in the fluid dynamic field has been found, from 1926, when he and Margaret Stimson gave the exact solution for two trailing spheres at constant distance. This motion is now known to be unstable, but was perhaps not then, since it is not discussed.

Besides this thermodynamic reflection, Jeffery's work, however, clearly falls within the micro-hydrodynamic tradition. This tradition goes back to the middle of 19th century when the Navier-Stokes' equation (then named Navier-Poisson's equation) had been definitely established by George Gabriel Stokes in 1845 [41], and directly been applied for a sedimenting sphere in 1851 [42]. As the title of Stokes' impressive memoir indicates it was a theoretical sequel to the very important longitude problem of navigation, whose practical solution was developed in the 18th century by the clockmaker John Harrison [43]. Stokes made hydrodynamics "micro" by applying his solution to raindrops. Hydrodynamics seems to soon have reached its mature form by the mid 19th century. Kirchhoff's book [14] from 1877 could have been written today. The micro-hydrodynamic development continued with sedimenting ellipsoids by Anton Oberbeek [44] in 1887, movement in dilational flows by Einstein [12, 17] around 1900, close to walls by Smoluchowski [31] around 1910 until Jeffery came with his contribution in 1922 [ibid.].

One of the better-known fluid dynamicists, Geoffrey Taylor [45] (1923), professor in Cambridge, realised that he could test Jeffery's conjecture regarding the final orientation of the ellipsoids with his large Couette instrument. The very practical Taylor made tiny aluminium ellipsoids (prolate and oblate, lengths from 1 to 3 mm) with a lathe, placed them in his instrument filled with waterglass (a Newtonian fluid) and indeed found that Jeffery's suspicion was right, but seems to have missed the point in his reasoning by trying (in vain) to find an explanation of it within hydrodynamics, i.e. in Navier-Stokes' equation. This was perhaps not exceptional at that time, since the relevant thermodynamic break-through came in 1931/32 when Lars Onsager [46, 47] (Nobel Prize winner 1968 for the discovery of the reciprocal relations) presented his famous theory based on micro-reversibility utilising Einstein's fluctuation theory, in turn going back to the ideas of Kelvin (then William Thomson) [48] from 1854. Still in 1938, however, the physicist Johannes Burgers [49] in Delft had problems in understanding the final orientation result from a hydrodynamic point of view, but “saved him” by suggesting that, at the molecular level in which he was interested, Brownian motion effects dominated.
This strange debate continued well into the 1950’s, when Saffman and Batchelor (Taylor’s successor on his Cambridge chair) managed to convince Taylor that his old results from the 1920’s had been caused by viscoelasticity, which then was in the air through Weissenberg’s recent experiments. And still in 1967 Goldsmith and Mason came up with the strange idea that some elongated particles oriented themselves for maximum dissipation rate and some for minimum. But two years earlier Verhás in István Gyarmati’s new Hungarian thermodynamic school had shown that Navier-Stokes’ equation follows from Onsager’s principle of least energy dissipation rate for viscous/inertial systems.

Returning to Jeffery he had also suggested, to avoid the above-mentioned problems with the viscosity, the use of an initial random orientation distribution of the particles. He gave no mechanistic motivation for this, but Brownian motion is close at hand. Particle orientation in flow fields was studied both theoretically and experimentally in the late 1920s and early 1930s with suspended material becoming double-refracting upon deformation (kautschuk, polystyrol, gelatine) by Walter Kuhn in Karlsruhe, Eugen Guth and Friedrich Roland Eirich et al. in Vienna. Particle rotation due to Brownian motion was treated by Richard Gans in Königsberg and by Eisenschitz at the Kaiser Wilhelm Institut in Berlin. (KWI, founded in 1911 on industry donations at the centenary jubilee of the Humboldt University in Berlin, renamed Max Planck Institut after WW2). Also Burgers developed this mathematically fairly thorny subject further.

A central question for such systems concerns their thixotropy, i.e. why stress falls after the initial stress increase caused by a step increase in deformation rate (and vice versa), leading to pseudoplasticity. Goodeve discussed possible mechanisms, e.g. shear orientation, reduction of particle size by shear, interaction between the particles, etc.

6 THE MACROMOLECULAR TRADITION

The dust after the battle of atoms had hardly settled when another conflict blew up, about macromolecules and this time not at all friendly. The influential chemist Emil Fischer (Nobelist in 1902 for the Fischer-Tropsch method) had declared that organic molecules with a mole weight greater than 5000 grams do not exist, and Wolfgang Ostwald, Wilhelm’s son, postulated that starch, cellulose, silk, rubber etc. were colloidal aggregates. X-ray crystallography was proposed in 1908 by Max von Laue (Nobel Prize already 1914 for this) at KWI in Berlin-Dahlem, and was developed by the Braggs, father and son during World War I (both Nobelists 1915 for X-ray spectroscopy, the latter Cavendish professor in Cambridge). Such studies, e.g. by Nishikawa and Ono in 1913, did not reveal unit cells larger than those of ordinary molecules, thereby supporting the aggregate theory.

This was the established view when in 1917 Hermann Staudinger declared that such substances instead consisted of giant molecules of covalently linked small-molecular constituents and started campaigning for his idea (Nobel Prize 1953 for his work in this field). Finally, the academic establishment, among them Fritz Haber (Nobel Prize in 1918 for the Haber-Boschprocess, protests from UK because of his recent role in the war, director of KWI, Berlin-Dahlem) thought that the matter ought to be discussed at a symposium in Düsseldorf to which Staudinger would be invited. In the background figured personal antipathies between Haber (inventor of the modern gas war) and Staudinger (staunch pacifist who openly had attacked him for this). The plan seems to have been to gather Staudinger’s opponents and crunch him at the 1926 symposium, but the plan back-fired and Staudinger earned more proselytes than he lost, among them the symposium chairman Richard Willstätter (Nobel Prize in 1915 for the chlorophyll structure).

A participant was Hermann Mark, employed in 1922 by Haber at the new KWI Institute for Fibre Research (Faser Forschung). Fibre then meant textile fibres. Under Michael Polanyi he had embarked on X-ray crystallography studies of various natural fibres such as cellulose and silk. At the symposium, Mark had not yet made up his mind on the central question. He later developed a compromising view, but finally accepted Staudinger’s macromolecular idea. Different opinions, however, developed between them regarding the nature of the macromolecules. Staudinger thought that their backbones were stiff whereas Mark held the view that they were flexible. Here time proved to be on Mark’s side.

After a session as research director at IG Farben, the energetic Mark (nicknamed “der Geheimrat” because he was just the opposite;
lively and informal, alpinist and once a member of the Austrian soccer team) was forced in 1932 to give up his post for political reasons. Hitler’s Machtübernahme in 1933 was foreseen and Mark’s mother was Jewish. He was instead appointed professor in physical chemistry at the University of Vienna. There he designed world’s first curriculum of polymer physics [64]. Mark’s main interests were polymerisation mechanisms and the viscosity of polymer solutions; a method used by Staudinger [65] to estimate the molecular weight of the macromolecules, but with a rather uncertain theoretical foundation, Eisen-schitz [66] and Burgers [49]. For dilute macromolecular solutions, he had found a linear relationship
\[
\frac{\mu}{\mu_0} = 1 - cM
\]
between the specific viscosity \(\mu\), concentration \(c\), and the macromolecular weight \(M\), using an effective radius concept (Wirkungsbereich, cf. the critical concentration concept of Mason in the 1950’s, see Part 2). This model had to be modified if the macromolecules were flexible; leading to the Mark-Houwink equation. Mark’s rheological expert was Friedrich Roland Eirich, who had completed his thesis in 1929 and then continued as assistant under his professor Wolfgang Joseph Pauli.

Mark at I. Chemische Laboratorium and Guth at the Institut für theoretische Physik der Universität Wien in 1933 made an inventory of the state of the art and concluded that experimental data were lagging behind the theoretical development [67]. An interdisciplinary co-operative research was organised, along the same lines as that done by Haber in KW1 Berlin-Dahlem. (The idea of scientific branch institutes originated from the needs of the textile industry in England in the 19th century, the first being at Shirley in Manchester.) The results were reported between 1936 and 1937 in an impressive series of articles in Kolloid-Zeitschrift under the heading “Untersuchungen über die Viskosität von Suspensionen und Lösungen”; Guth [57, 68], Krasny-Ergen [69], Guth and Simha [70], Eirich, Margaretha and Bunzl [58, 71], Simha [72], Eirich and Goldschmid [73]. It covered different aspects such as electroviscosity, wall-effects, the influence of Brownian motion, fibre suspensions, inertial effects, etc. For example, Eirich et al. [58] also presented cinematic studies of the motion of different types of fibres in various flowfields, cf. Henri [27]. On 13 September 1937, Eirich and Robert Simha [74] submitted an article about the interaction between ellipsoids by applying Maxwell’s treatment for gases, i.e. all molecules were assumed to be fixed except one that is shot as a projectile through the assembly. They found that the effective collision cross section, “Wirkungsquerschnitt,” increased linearly with axis ratios larger than about 2 to 3. This is the first work about a more detailed mechanism of the interaction between two elongated particles known to the author.

Anschluß came on 14 March 1938. Mark, partly because of his friendship with Chancellor Dolfuss who was murdered in 1934 by Nazi conspirators, was dismissed from his professorship and imprisoned by the Gestapo, but managed to bribe himself free (a years professor’s fee) and flee with his family via Switzerland (passing the border with the car front draped with a swastika and his means hidden as platinum thread in clothes hangers), first to Bragg at the Cavendish Laboratory and then further to Canada.

There he worked at Canadian International Paper’s plant in Hawkesbury for two years on the pulp process, cellulose acetate and viscose. Viscose for tyre cords then was the economically most important product for the sulphite pulp industry before nylon, polyester and finally steel took over. The viscose work led to contacts with DuPont, where he later moved. There, tire projects led to contacts with the Polytechnic Institute of Brooklyn in 1940, where he soon moved again. At Brooklyn Polytech Mark organised the polymer research that in 1947 was given the name the Polymer Research Institute (PRI). Mark also gathered around him refugee scientists from Europe, among them Eirich (Figure 5).

Eirich had become Privatdozent in early 1938 at Mark’s department but already in July 1938 he was forbidden to lecture because a grandmother was Jewish. Eirich also managed to escape to Cambridge where he worked for some time. When the hostilities started, foreigners, including Eirich, were interned in camps as enemy aliens, and Cambridge was declared to be protected area closed to foreigners. In August/September 1940 he was deported on HMS Dunera to Australia, while his wife remained in a camp in 23974-8 Applied Rheology Volume 18 · Issue 2

Figure 5: Hermann Mark (left), Roland Frederick Eirich.
England. For two years, he worked at the University of Melbourne on research into explosives [75] before he was allowed to return to Cambridge in 1944. In 1947 he joined Mark at PRI, where he continued with polymer research.

7 THE SEQUEL OF WW2

In the early 1950’s, Eirich was sent to Europe to re-establish contacts and gather information. Mark, through his work in the pulp and paper branch, personally knew Börje Steenberg (who confirms that he indeed was very non-Geheimratian), professor in Paper Technology at KTH and director of the neighbouring Swedish Paper and Pulp Research Institute, STFI. Viscose research at that time was also important in Sweden and at STFI. This research was headed by Erik Hägglund, professor in Cellu-
lose Technology, and later by Erich Treiber (viscose expert recruited by him from Graz in post-war Austria, where this research was located between the wars and after, but also at the chemistry department at the Vienna university). A seminar was arranged where Eirich spoke about ongoing research at PRI and corresponding information was presented about the activities at KTH/STFI. Amongst other things, a film was shown about fibre motion in shear fields that Steenberg just had got from Stanley Mason, professor in Chemistry at McGill and also employed at the branch research institute Paprican/Montreal, with whom Steenberg cooperated and exchanged research students. During this period Steenberg visited America at least once a year, and then normally went up to Cambridge and found the film on exactly the same spot where it had been left in the well-known chaos at Cavendish. When the film box was opened for the first time back at KTH it was found that it had fragmented and could not be shown. At KTH a professor in photography was able to help, having just managed to save undeveloped film rolls after 30 years in the Arctic after the unsuccessful and tragic attempt to reach the North Pole in a gas balloon by Salomon August Andrée in 1897. He restored Eirich’s film, which confirmed what he had said. This film was mixed with Mason’s film and regularly shown in the course in Paper Technology at KTH during Steenberg’s professorship until 1979. Then it was neglected.

In the summer 2005 the author, with the ambition of having Eirich’s film transferred to CD and publishing it, managed to identify it in a large heap of unmarked film rolls at the department. He and Steenberg held Eirich’s film in their hands and looked at the first frames with the German text against the daylight. When they tried to play the film in one of Paper Technology’s two old film projectors the feed did not work and the film started to melt, so they did not dare to continue. The other projector lacked an objective. But before a lens could be borrowed at KTH, the film (unmarked in a heap among other unmarked film rolls in a room behind two locked doors accessible only with high-priority keys) was suddenly gone when a retiring person (the only outsider who was informed what was going on) left the department and moved to a nearby research institute. So, now Eirich’s film that survived Anschluß, flight over the Alps, Blitzed, fragmentation at Cavendish, and restoration at KTH was gone again!
APPENDIX: A METABOLIC SCHEME FOR FIBRE FLOW RESEARCH

The scheme in Fig. A1 is an attempt to illustrate the complex development and influences in fibre flow research. Full lines mark "traditions", grey thick line marks the main theoretical tradition in fibre flow and a broken line marks personal influences.

The continuation of the manuscript entitled “The Nonlinear History of Fibre Flow Research: Part 2. Continuation, Reflections and Suggestion” will be found in the next issue of this journal [76].

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