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THE ROLE OF FUNDAMENTAL RESEARCH IN THE MANUFACTURE OF PAPER

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Abstract

A subjective evaluation of the role of fundamental research in the manufacture of paper over the past 25 - 30 years traces the roots of some important inventions back to fundamental research endeavours. During this time, technical progress in paper manufacture has been both rapid and multifaceted. Fundamental research in relevant areas has resulted in higher productivity, improved process and product control, and better design of the paper-making process and the associated equipment.

These improvements clearly indicate an important role for collective efforts, guided by far-sighted industry leaders, in the area of fundamental research. The assignment of scientists by industry leaders to carry out this research in areas recognised as bottlenecks to technical development appears to have led to many of the important developments. Because improvements to the paper-making process are expected to yield returns to the paper industry, the responsibility for initiating, funding, and guiding fundamental research in appropriate areas must rest with the paper industry.

Symposia of a fundamental nature have been important in reviewing the state of the art, thereby exposing not only knowledge but also the notable lack thereof in essential areas.

Introduction

Fundamental research into any applied area, not least into any area with a definition ending in 'manufacture' or '-making' can play a significant role in only two respects. One relates to furthering our understanding in general and transmitting this improved understanding to students and other people active in the specific area. This role of fundamental research is acknowledged here as probably the more important in the long run. It is difficult, however, to measure its importance, and therefore it will not be discussed here. The other role of fundamental research relates to results that are, in fact, implemented in the manufacturing or '-making' processes. Results of fundamental research which are <u>widely</u> implemented, offer some discernible advantage over previous technology, and so are significant in some usually economically measurable respect. The word <u>widely</u> is important.

Since the sheer volume of results, inventions and implementations in the paper industry over the past few decades precludes any exhaustive treatment, I adopted the following criteria in my search for examples:

- limit the time span to the past 25 - 30 years
- limit topics to those discussed at industry-wide conferences on fundamental research
- limit the number of subjects to a few, well documented in the literature.

Having thus decided on the criteria, the task in hand was to decide on the results and conclusions to be drawn, do some preliminary research, and write an abstract. With these tasks out of the way some serious reading and interviewing could be done, preliminary results and conclusions were slightly modified, and the following report written.

Results and conclusions

1. Truly significant discoveries and developments have resulted, and will result, from fundamental research efforts relevant to the paper manufacturing process.

2. Truly significant discoveries and developments do not come out of thin air, but out of need.

3. Some of the greatest advances have been made by applying techniques borrowed from other fields. The difficult part of the problem has not been finding a solution but a proper definition.

4. Once the problem has been properly defined it is usually amenable to quantification. This is what transforms the art into science and/or technology.

5. Improvements to the paper manufacturing process are expected to yield returns to the paper industry. Hence, the responsibility for initiating, guiding and funding fundamental research in appropriate areas must rest with the paper industry.

6. Because most improvements to manufacturing processes require heavy investments in capital equipment and the paper industry generally is not in the capital equipment business, suitable transfer mechanisms and incentives must be devised in those cases where the results are to benefit the industry as a whole.

7. Well-organised symposia of a fundamental nature expose not only knowledge but the notable lack thereof in certain areas. This stimulates R & D efforts, possibly by making technical leaders of industry more aware of needs and opportunities.

8. Access to relevant equipment plays a most important role in problem definition as well as in evaluation of proposed solutions and performance of key hardware.

9. The experienced technologist, who knows all the answers and how to solve all the problems, is a most valuable asset, after its conception, to a fundamentally new concept and initial demonstration.

10. The era of innovation based on fundamentally new insights is not yet past, not even for the paper industry.

The following sections exemplify how discoveries and inventions of great practical significance to the manufacture of paper have been made and implemented, though the descriptions there are in many ways incomplete. Notable exclusions are important summary and overview papers, since the focus is on early, initiating contributions.

The hurried reader may turn to the last section: "Who Needs Fundamental Research?"

Some Case Studies

1. HEADBOXES AND FIBRE SUSPENSION FLOW

The performance of a paper machine headbox is central to the performance of the whole machine, primarily with respect to the development of proper profiles in the machine and cross machine directions. But it also exerts a very direct influence on paper properties through control of the fibre orientation and formation of the sheet, not to mention its role in inducing flow instabilities for later amplification on the wire.

The two most basic functions of a paper machine headbox are to spread the flow of a fibre suspension evenly across the width of the paper machine, and to impart a velocity to the suspension approximately to match that of the wire.

Scenario

Twenty-five to thirty years ago paper machine headboxes had progressed from the early kneading-trough-plus-sluice-gate type to high open monstrosities with multiple baffles and, sometimes, perforated distributor rolls. Closed, air-padded headboxes with multiple distributor rolls were coming into use.

The scenario in 1954 was one where headbox design had evolved gradually and was based on combinations of tradition with invention and innovation. There was a growing awareness that fibre suspensions have rather special properties and that turbulence plays a role.

The Fundamental Research Conference in Appleton, 1954

Papers relating directly to the above subjects were on the programme for the fundamental research symposium co-sponsored by the fundamental research committees of TAPPI and CPPA, and held at IPC in 1954.

Mason had performed experiments with fibres in water and other media, and the paper presented in Appleton(1) was one of the first in his now famous series on fibre motions and flocculation. It was a very basic study of single fibre motions in sheared suspensions and of collisions and interactions between fibres, spheres and rods. Work performed by Mason and his co-workers had led him to the conclusion that "at the fiber concentrations and under the conditions of flow met in practical paper-making, fiber bundles are generally, but not necessarily exclusively, formed by a purely mechanical entanglement of fibers as a result of the characteristic translational and rotational motions of individual fibers and fiber aggregates in velocity gradients". He also introduced the concept of "critical concentration", i.e., the fibre concentration above which fibre-fibre interactions are to be expected, and notes that "the critical consistencies are well below those of conventional paper-making stocks".

Van der Meer[2] noted the requirements on the jet and reviewed the then common knowledge of the flow properties of fibre suspensions, and although he certainly mentioned and explained the reasons for variable pressures, velocities and directions of flow in headboxes, he neither related this quantitatively to basis weight profile variations nor did he suggest the application of now `obvious´ techniques from other fields of fluid mechanics to cure the situation. This was probably because, at the time, the seriousness of the problem was not apparent to him.

The seriousness of the basis weight profile problem was becoming very apparent to some leaders of the industry, however, as machine speeds began to approach 600 m/min (2,000 fpm). Burkhard and Wrist, then with QNSP Co, presented a paper entitled "The Evaluation of Paper Machine Stock Systems by Basis Weight Analysis"[3], where they laid down the foundation for modern evaluation of profiles by application of analysis of variance to determine the components of basis weight fluctuations. Their work gained considerable momentum when they applied the then-new technique of measuring the basis weight profile of strips of paper by means of a beta ray gauge.

In Appleton in September of 1954 all the essential ingredients were assembled:

- requirements on the jet and state of flocculation
- awareness of turbulence - flocculation interactions
- awareness that basic fluid mechanics does apply also to headboxes
- awareness, by at least some people in the audience, of the importance of stable basis weight profiles
- a new tool and a new technique for measuring and evaluating basis weight profiles

The ensuing development was rapid, multifaceted, extensive and very significant to the paper industry.

The Fundamental Research Symposium in Cambridge, 1957

Forgacs, Robertson, and Mason[4] showed that even fairly dilute (i.e., down to headbox consistencies) fibre suspensions exhibit elasticity and strength, and that the cohesion is caused mainly by mechanical entanglement. They also indicated the relationship between fibre network properties and the flow behaviour of fibre suspensions and pointed out that "mixed" and turbulent flows involve the breakdown of the fibre network by turbulent stresses. This is where the quantification started of the plastic flow concept described by Van der Meer in Appleton , which he related to certain aspects of headbox performance.

The Fundamental Research Symposium in Oxford, 1961

Z. J. Majewski[5] reviewed results of research into how the elements of various sheet forming processes affect the structure of the sheet, particularly how the structure varies in the thickness direction. O. Andersson[6] reported on the increase of flocculation with time in relatively dilute suspensions, and also demonstrated how increasing rates of drainage improve the formation of the resulting sheets. Robertson and Mason[7] were aware that "at headbox concentrations in 'plug' or 'frozen' flow, one deals with a single, continuous floc, within which there are statistical variations in concentration that reflect the previous history of the sample, particularly its history of turbulence." They also reported on experiments in which tagged fibres were added at the slice and at various positions in the approach flow system. The fibres could then be located by semi-automatic means in the finished sheet. From such measurements they could evaluate small- and large-scale dispersion effects. It was evident from their results that there existed very intense and large scale disturbances in the studied headboxes. Once again, quantification had been made. The unbelievably uncontrolled state of the flow had been exposed, and this stimulated much more research in several places.

P. E. Wrist , then with the Mead Corporation, reviewed work done by himself and others relating to the fundamentals of headbox performance. Wrist had, at least partially, quantified gross flow, flocculation and stapling phenomena in and around distributor rolls, and turbulence effects in the jet. He related his results to those obtained by H. W. Bennet[9] of the Kimberly-Clark Corporation, who had measured velocity and turbulence produced by various kinds of distributor rolls operated in a wind tunnel. Wrist also related his measured results to effects observed on a pilot paper machine and in the finished sheet off the machine, and thus could assess the relevance of the various phenomena. By knowing about the needs, having insights into the fundamentals, quantifying observations and having access to relevant experimental equipment, Wrist could both quantify and assess the relevance of the results as well as better define problems and opportunities.

Cross flow spreading

In 1956 Baines, Nicholl, Cook and Mardon[10],then with North Eastern Paper Products Ltd., published the first paper on single-sided inlets for headboxes. The key paper on cross-flow spreading, by Mardon et al.[11], appeared in 1963. The authors discussed the results of experimental and analytical research, and of measurements in industrial installations, to give a comprehensive picture of performance. The advice they gave on design procedures has proved to be of immense value in raising machine speeds above 600 m/min. G. Gavelin, who worked with Mardon, improved on the idea, and already in 1960 the first article describing a successful installation of the improved version appeared in Tappi[12]. A.D. Truffit of APM Ltd summarised the state of the art in 1975[13]. It seems clear that once the problem was properly defined as one in elementary fluid mechanics, the basic solution became apparent. Modern flow spreaders are a result of fundamental research, because knowledge of the fundamental requirements of the process was necessary , as well as knowing where in the engineering world a solution could be obtained.

Secondary Flow Phenomena

There was plenty of opportunity for secondary flow phenomena to occur in the old headboxes. Many of these were reviewed by Van der Meer(2) in Appleton in 1954. His review probably prevented lots of trouble for the paper industry in later generations of headboxes, but it certainly did not prevent all. At the 1961 symposium, Robertson and Mason(7) and Wrist(8) reviewed other types of instabilities and effects and their potential or documented effects on sheet formation. This about closed the book on secondary flow phenomena. Paper machine builders and users had access to sufficent background material of a fundamental nature to avoid detrimental effects due to secondary flows. The fact that it took more than a decade for this knowledge to permeate the industry and be successfully applied in practice on new installations is another matter, as is the fact that quite a number of old headboxes suffering from secondary flow instabilities are still around.

Fundamental Research on Turbulence in Headboxes, or The Demise of the Distributor Roll

The initial concept of a distributor roll was one of deflocculating the stock by letting it pass through a perforated plate, rolling up the plate into a roll, and rotating it slowly for cleanliness. Bennet(9) regarded the roll as a turbulence generating device, and quantified its functions in this respect. Through his investigations and those by others, notably Wrist and

Mardon, who discussed them at the 1961 symposium, it became evident that the designer was faced with severe limitations: only a narrowly defined range of designs would give acceptable hydrodynamic stability without stapling, and the prospects for improvement of the state of flocculation were not bright.

After the 1961 symposium a number of people realised that the key to future development lay in gaining control of the turbulence by some other means. Kimberly-Clark and Westvaco developed headboxes which were put into successful industrial operation. J. Parker, of the Beloit Corporation, investigated in a very fundamental manner the possibilities for, and limits to, dispersion of fibre suspensions at normal and elevated headbox consistencies by means other than perforated rolls. He showed that small scale turbulence was needed for small scale dispersion and that the scale of the turbulence was directly related to the size of the conduit. He summarised some of his ideas and reviewed some of the struggle towards small scale disperion in a paper read to the 25th General Conference of APPITA in 1971[14].

Joe Parker and his colleagues at the Beloit Corporation had figured out an ingenious and, in retrospect, very straightforward way of diminishing the scale of turbulence in fibre suspensions. They separated the functions of flow spreading, coarse deflocculation by large scale turbulence generation, and fine scale dispersion. The coarse deflocculation function without fibre stapling had been previously obtained and published[15] as a result of a truly fundamental research effort. Fine scale dispersion was obtained by passing the stock through several superimposed and converging channels. At the end of the convergence the channels are very thin indeed, so that large-scale turbulence is effectively suppressed. In this way, based on a clear sense of <u>need</u> and direction, and on <u>fundamental research</u> and <u>access to relevant resources</u>, a step improvement was made, an order-of-magnitude improvement in basic headbox performance was achieved. And the eventual demise of the distributor roll was assured.

Slice and Jet Geometry

The ability to predict very accurately the trajectory of the jet emerging from a headbox is essential both at the design stage and for the successful automation of paper machine operation. Both on fourdriniers and on twin-wire formers exact positioning of the jet for all combinations of speed and jet thickness is essential to controlled and predictable operation. Headbox jet geometry as a function of slice setting had been analysed by H.C. Nelson (16) of the Kimberly-Clark Corporation. On the bases of dimensional analysis and experiment, he laid the groundwork for quantification of these relationships. Later, D.W. Appel and Y.S. Yu(17) made an extensive theoretical analysis of the subject, sponsored by the Kimberly-Clark Corporation.

Anyone who has read the report by Appel and Yu realises that it represents an excellent piece of fundamental research work. It is highly academic in nature, yet provides the foundation for the solution of the very mundane problems of prediciting efflux conditions from dams and headboxes. It is a good example of successful fundamental research, initiated, (partially) funded, and guided by the paper industry to satisfy a specific technical need. The attention of the technical community of the paper industry was drawn to it at the 1961 Symposium.

2. FROM TABLE ROLLS TO FOILS

Draining the water from a very dilute fibre suspension is a process which is, in fact, incidental to the papermaking process, but nevertheless necessary. The technical objectives of the paper-making process are to form, from fibres and minor constituents, and to deliver, a sufficiently good sheet. If formed from water no binder is necessary for the basic grades, but high dilution factors have to be used because of the network-forming and flocculating characteristics of fibre suspensions. This allows the fibres sufficient freedom of motion so that, if the suspension is suitably agitated, they can be relatively independently deposited in the sheet, and even preferentially deposited in areas of below average basis weight. Dewatering is a necessary corollary.

Scenario

Twenty-five to thirty years ago the speeds of news-print machines were, in some cases, approaching 600 m/min (2,000 fpm), and substantial problems were encountered with control of the flow on the wire. The fact that table rolls contribute greatly to drainage by generating a vacuum in the outgoing side of the nip might have been recognised by some[18] for many years, but had not been put on a sound scientific base. At that time, Peter Wrist was working with W. E. Bennet at the The British Paper Industry Research Association in Kenley, Surrey, England. One of the research areas was forming, primarily the forming of newsprint, and in 1952, Wrist[19] described theoretical aspects of water removal by a table roll, which earned him the first prize in the 1954 C. Howard Smith Medal Award Competition[20].

The Fundamental Research Symposium in Appleton, 1954

C.C. Porter[21], then at Southland Paper Mills Inc., showed the first (?) high speed pictures of instabilities on the wire of a (then) high speed news-print machine (1,500 fpm, 450 m/min). He showed vortices and waves coming out of the headbox and being modified into streaks and spouting on the wire.

Ingmanson and Whitney[22] presented the concept of scientific filtration resistance, its components of specific surface and specific volume, and discussed how it might be applied to the characterisation of stock and, possibly, to drainage on the paper machine.

G. F. Underhay[23] had succeeded in reproducing in the laboratory the kind of two-sidedness produced on industrial paper machines by introducing in a sheet machine a rapid oscillatory relative motion between the wire and the draining water beneath it. He concluded that medium and high speed table roll action squeezes water into the underside of the sheet on the in-going side of the roll. This disturbs and washes the underside of the immature sheet, and fine material is loosened and preferentially removed from the underside in this way. He had tried to eliminate the effect by use of meshed table rolls, scrolled table rolls, table rolls with water repellent surfaces, and stripper or scraper bars instead of table rolls. There were some indications of improvement, but also difficulties, such as reduction of water removing properties, increased wire wear, the need for driving doctored rolls, etc.

W.E. Bennet[(24)] from BPBIRA presented results of quantitative studies of water removal on an industrial news-print machine operating at 700 fpm (210 m/min). He included references to work by Wrist, who by then had moved to Canada and was present at the meeting.

Wrist had been working with Bennet at BPBIRA in the area of forming, particularly of newsprint. Outside pressures had caused Bennet to ask Wrist to produce a good piece of research and an article within two months. Peter recounts:

"... A program to study paper machine drainage by statistical analysis was under way, but we had no theoretical work on which to depend. The idea that suction must exist in the downstream table roll `nip´ came one day during a mill visit in which the regularity of the drainage curtains on the slow speed machine caught my fancy. A library search of recent literature unearthed Sir G.I. Taylor's paper[(28)] and the similarity between curtains and his work was recognised. This led to the conclusion that a vacuum of $1/2\ \rho V^2$ must exist in the table roll nip. The problem was to prove it mathematically and to test it in practice. Unfortunately, the R & D lab burned down at this juncture and the only resources were the metal frames of the laboratory benches, the facilities of the woodworking and metal shops and a heap of burst testing diaphragms in the storeroom; BP & BIRA was big in the burst testing business in those days.

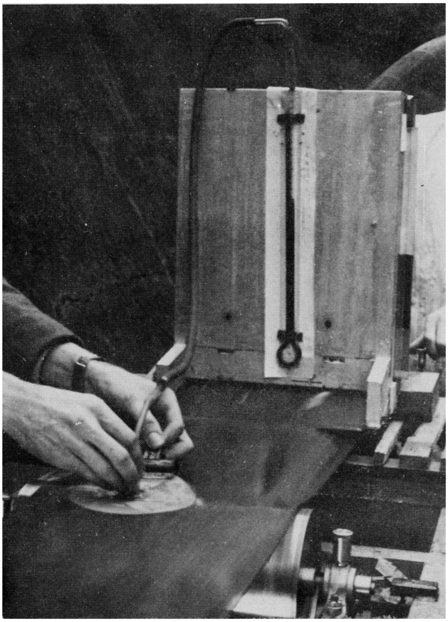

Fig 1—Purely fundamental research on a practical subject. The model headbox is mounted on a metal bench frame and is fed from a hose connected to the swimming pool filter system. The probe, made of a Mullen Tester Diaphragm, is held in position by the investigator. *(Courtesy of the investigator, P. E. Wrist)*

One metal bench frame was used as a stand for a table roll, see Fig. 1: a wire belt was stitched together: a hand operated wire guide built (man in photo behind headbox is working the wire guide): a headbox of primitive design built and the whole thing erected on the swimming pool deck (also undamaged by the fire). The pressure probe was gradually drawn from downstream of the roll towards the headbox. The position was measured by a ruler and the pressure by the manometer as shown. The vacuum was measured through the wire, no fibres, just water was used. The graph, Fig. 2, shows one set of readings with the table roll running at wire speed and also with it stopped.

The hands holding the probe in the photo are mine. Note the use of a bulldog clip for safety. The burst tester diaphragm is the circular rubber sheet sealing the nip. The pressure probe used the small hole in the in the centre of the diaphragm. The only sophistication was the grease cup on the table roll bearings. The hose feeding the headbox coming from the swimming pool filter system can be seen in the background...."

Two months later the research report, and the article, were ready(19). This was in 1952. The theory of water removal by table rolls had been born.

These, and results given in a later publication[20], earned him the 1954 C. Howard Smith Medal.

In the discussion following Bennet's paper, B. Steenberg, STFI, Sweden, brought up the question of wire wrap around the table roll, measured by him and J. Bergström on a pilot machine. Bennet remarked that people had observed this for a long time, but had apparently attributed it to surface tension forces. Now it became apparent that it was caused by the pressure drop across the web and wire caused by the suction action of the table roll.

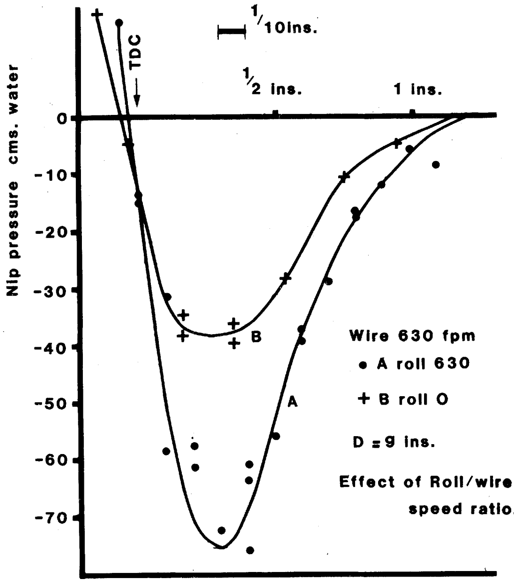

Fig 2—The first quantitative data on table roll suction. Results obtained by means of the equipment shown in Fig 1. Note that the suction decreases to half the original value when the roll rotation is stopped; the basic idea of the drainage foil? *(Courtesy of P. E. Wrist)*

Development of the Foil and its Theory: The 1956 CPPA Convention

On Dec.27, 1955 Burkhard and Wrist[25] applied for a patent, for "---a unit composed of transversely positioned members each of which has an acute-angled leading edge, a flat portion in supporting engagement with the wire, and a trailing portion which diverges from the wire at a small angle." The drainage foil was an officially recorded idea.

In January of 1956 the same authors[26] presented a paper at the annual CPPA convention, where they described not only sophisticated and very exact measurements of table roll drainage at speeds up to 2500 fpm (750 m/min), but also a cross section of a stationary foil and experimental results relating to its drainage function. They even indicated a slight wire wrap on the foil.

Sir G.I. Taylor(27) also presented a paper on drainage at a table roll. His attention had been called to the hydrodynamic problems of the paper machine by J. Mardon, who sent him Wrist's earlier articles. He had approached the theoretical problem in a somewhat different fashion, and included an entirely different treatment of the instability of the wedge of water on the underside of the wire. He had also performed experiments on this aspect in the Cavendish Laboratory.

Burkhard and Wrist received a preprint of Taylor's paper during the final assembly of their own, and so had the possibility of checking out the modified theory against their measurements. Discrepancies between theory and measurements were moderate, and could largely be explained by effects of wire wrap around the roll, which Taylor did not consider. By and large there was agreement between theory and measurements, but Sir G.I.Taylor had contributed to a more fundamental understanding of the effects involved, not least to the instability of the water in the wedge at the downstream side of the table roll. This became important to the more complete understanding of the action of foils.

Moreover, work done by Sir G.I. Taylor(28) previously quoted by Wrist and combined with his own observations on the high speed pilot machine at Baie Comeau, explained the basic mechanism involved in stock spouting on the wire. It is a function of the wire wrap on the table rolls and the large acceleration that the stock on the wire is subjected to when travelling along the non-linear path of the wire. Bukhard and Wrist(26) note that "the disturbances increased far more in going from 2000 fpm to 2500 fpm than from 1500 to 2000 fpm, and at the higher speed are already often a limiting factor of formation. It is suggested, therefore, that before any major speed advances can be made with the conventional fourdrinier method of making paper some new means of drainage to replace table rolls is needed". They had realised the need, and thought that the answer might be the foil. Moreover, they showed that stock spouting on foil sections of the pilot machine was much less than on the sections with table rolls. In addition, the retention on the foil sections was much improved.

Implementation

At this point the idea of the drainage foil was ripe. It had grown out of a need to understand and predict the performance of new and faster paper machines. The fundamentals of drainage by table rolls (and foils) were understood. It was clear that the real problem was not of drainage capacity per se, that was incidental, but of obtaining stability of stock flow on the wire combined with gentle micro-scale turbulence for optimum dispersion. This can almost be characterised as a spin-off result, but a most important one, and one which came quickly also because of access to relevant experimental equipment.

Implementation of the idea was another matter. The experimental foils were made of brass, and even in their report Burkhard and Wrist noted that there were signs of wear on them. When they were tried in continuous operation, they wore out very rapidly. Chrome plating ruined the bronze wires instead. This was the time when the first plastic forming wires were being tried. They were then very flexible, and one of the difficulties in using them was that they wrapped round the table rolls much more than did their bronze predecesors. This gave rise to very poor retention, amongst other problems, so the fabric manufacturers were looking for means of obtaining " softer " drainage. As it turned out, stainless steel foils worked well with the fabrics, though there were still problems of wear and cost. It took several years, personal contacts with several manufacturers of fabrics, machinery, and paper, at least one lawsuit, and a lot of fine engineering, to arrive at the first approximation of what is today's standard for controlled agitation and de-watering on the fourdrinier.

The whole paper industry has reaped the benefits of these fine pieces of fundamental research. It all started with a somewhat undefined sense of need by the leaders of the British paper industry as they anticipated higher operating speeds. Since the most appropriate course of action was not obvious, the central research organisation was approached. They attacked the problem in three different ways: through mathematical modelling, small scale experimentation, and quantitative measurements on an industrial machine. The initial results were discussed and inputs received at a fundamental research conference. Two years later the champion of the project had moved the project into industry, and done further fundamental research work, had gained access to and made good use of relevant experimental equipment, and developed the fundamental concepts on which modern fourdrinier technology builds.

3. THE VENTED PRESS

The development of current wet pressing techniques is not as well described in the literature as the previously recounted subjects. Nevertheless, the developments have been very important economically, and do illustrate a pattern intermediate between the purely fundamental and the purely empirical approaches.

The Fundamental Research Symposium in Appleton, 1954

A. Nissan(29), then with the Department of Textile Industries, the University, Leeds, England, had been asked to review "the functions of the felt in water removal on the paper-making machine." That was the only paper at this conference dealing directly with the process of wet pressing.

There was hardly any real discussion of Nissan's review of wet pressing mechanisms, although time was available and invitations to discuss the subject were made. Nissan had exposed the almost complete lack of understanding of the fundamentals of wet pressing at the time. He had reviewed the literature, he had made some observations, and he had to interpret his observations "with a judicious amount of speculation." He summarised:

"It appears that at the entry into the nip the felt and paper are compressed and water is extruded, thereby reducing the total quantity remaining. The water which is extruded is unlikely to have come from the web for Jahn and his colleagues[30] have shown that the paper web can retain surprisingly large quantities of water under very high pressures for a considerable period of time. It will be assumed that, in fact, the water comes mostly out of the felt, though some may come out of the paper. Thus, in the nip both paper and felt must be considered to be saturated with water. ....As the sheet and felt leave the nip, both expand. The total quantity of water is then partitioned between web and felt........"

Nissan had done a beautiful piece of detective research, working only from widely available information and using his knowledge of fundamentals to interpret what his (and others') eyes could see. His interpretations may not have been correct in every detail, but they presented an entirely different way of looking at the process of wet pressing. One may speculate on whether the lack of discussion of Nissan's rather heretical statements at the conference was due to shock or inspiration. In any case, the ensuing development was rapid.

The Concepts Crystallise in Various Forms

O. Brauns and L. Jordansson, then at the Central Laboratory of the Swedish Paper Mills, seem to have reasoned approximately as follows:-

Suction press rolls have a beneficial effect on pressing results. But the results of Jahn, Barkas, and others show that the vacuum levels which can be applied can hardly have a direct dewatering effect at the dryness levels obtaining in a press nip. It may be the holes drilled in the roll cover that do the job.

Since they had access to relevant experimental equipment, in this case a pilot paper machine, they rigged a plain press with a perforated rubber mat travelling with and under the felt through the press nip. It worked in principle and they filed a patent application.

In the meantime P. Wrist had moved to the Mead Corporation, and was pursuing the development of foils, now in combination with forming fabrics. Jordansson, on leave of absence from the Institute in Stockholm, joined Wrist for a year in Chillicothe. Wrist realised that a thick rubber mat might not be needed, because the amount of water pressed out of the paper web was small enough that it could easily be accommodated within the mesh of a forming fabric. They installed a fabric run inside the felt loop of one press on a pilot machine. When the water was drained from the fabric by a suction box, the felt and the sheet dried up significantly. Eventually, a viable concept had been demonstrated. This development later became known as the Fabric Press. It has found rather widespread application, but mainly in Europe, because that's where its champion was. Otto Brauns and his co-workers continued the development work, and Otto, personally and for many years, promoted the concept and reviewed each potential installation.

J. Bergström, then at STFI, was convinced that relief of the hydraulic back-pressure in the felt, a concept later termed venting, held the promise of better pressing. He joined the Beloit Corporation for a one year period, and concentrated on a fundamental, experimental evaluation of the venting concept. Using a fairly rapid punch press as his basic tool, he evaluated the effects of various porous materials as backings for press felts. This was the beginning of the Ventanip^{R} press, later developed to fruition by E.J. Justus and his co-workers at Beloit. Since they could obtain patent protection, and the concept worked well, they had motivation to undertake the long and costly development work.

So, in 1957/58, not much more than three years after the Fundamental Research Symposium in Appleton, where so much ignorance of wet pressing fundamentals was exposed, the concept of the vented press had been developed and demonstrated on pilot machines. The developments had taken at least two different routes, but both were rooted in people with an excellent understanding of, and actively using, fundamental research concepts. They also understood the needs, and they either had, or gained, access to relevant equipment.

The Fundamentals of Wet Pressing

In 1960, B. Wahlström[31] published a very extensive investigation of press performance, where he outlined the basic mechanisms of water removal as they are perceived today. Water is squeezed from the paper web into the felt in the compressional phase, and some of this water is reabsorbed into the paper in the expansion phase at the outgoing side of the press nip. Building on work by Bergström[32], Howe and Cosgrove[33], Wilder [34], Yih and McNamara[35], and others, Wrist[36] summarised the state of the knowledge of the fundamentals of wet pressing as perceived by him at the International Symposium on Water Removal at the Presses and Dryers, CPPA, Montreal in 1964.

In 1969 Wahlström[37] gave another summary of the subject. By this time there had been a deluge of activities in the wet pressing field. More than fifty of his literature references refer to work done in the intervening years, 1960 - 1969. The reference list is dominated by contributions from research institutes and machinery manufacturers, but there are many from felt manufacturers and the paper industry. Some of the most fundamental work was done by university people, entirely outside the paper industry but sponsored by felt manufacturers and others. Wahlström during this time had had access to relevant experimental equipment both bench-scale and a full-size pilot machine at KMW. A very considerable effort was successfully expended on very fundamental investigations[38]. This was the period when the double-felted press was developed, including the ground rules for web handling and transfer, and when the Fabric Press and the first combination, closed-draw press, the so-called UNI-press, reached maturity. A direct spin-off was the development of a correct understanding of the two-sidedness that can be caused by pressing[39].

So, fundamental research on wet pressing led to many and important practical results, basically through improvements in our understanding of the relevant fundamental processes. The rapid transfer of this knowledge was due to the great needs and opportunities as well as to the mobility of key people, champions of the developments. It is interesting that a very large proportion of the key individuals started their work in post-graduate research of a rather fundamental nature.

Finally - Who needs Fundamental Research?

There are innumerable examples in the paper industry of ideas and technology which have been brought in from other fields and have been successfully applied. There are examples from the areas of fluid mechanics and the statistical theory of turbulence, the sciences of porous materials, surface and colloid sciences, thermodynamics, systems and control technology, and many, many others.

Many of the successful applications have been straightforward transplants, e.g., the centrifugal `fan´ pump to replace reciprocating types or scoops, the reciprocating beating machine, and later the rotating refiner, the whole areas of power generation and electrical drive technology, bearing and lubrication technology, operations and planning techniques, pollution control devices, and many others.

There is the intermediate class of `adapted´ technology, e.g. control technology, where the whole theoretical base is transplanted intact, but new sensors are needed as are improved process descriptions. Another example is screening and cleaning, where fairly extensive modifications of technology borrowed from other fields has been necessary.

Rapid and effective utilisation of new technology, that can be transferred from other fields with more or less extensive modifications require process know-how, good economic and common sense and a range of interests broad enough to keep in touch with areas outside the paper industry. It does not normally require any fundamental research per se, but particular applications may run into problems, which sometimes require a fundamental solution. The development of sensors is one example, the collection of fundamental thermodynamic property data of materials specific to the paper industry is another.

Then there is the class of technology which is specific to the paper industry, as well as being of central importance to it. Headbox development, forming, pressing, etc., are all good examples. Systems analysis, and developments for the control and optimisation of the process, and for elimination of pollution sources are others. Some of these are relatively straightforward engineering tasks, but there has been, and probably still is, plenty of opportunity for radical developments of great potential value. Most of these opportunities will not be realised unless someone with at least a general knowledge of the paper industry sets out to question the fundamentals of what we are doing today, and at the same time brings knowledge from other fields to bear on our problems, not for a `quick fix´, but to learn, in new ways, what the real problems are. Once defined, the problems can usually be solved, and the paper industry takes another step to improve and maintain its competitiveness.

The costs of producing a ton of paper will continue to increase. This is a safe prediction, and is based on the increasing cost of many factors. Other media for communication and distribution will be competing with paper for market shares. The paper industry must develop continuously to stay competitive. For the individual business unit the highest impact per unit of development cost is usually realised by implementation of modern technology for high volume production of standard products or by developing a competitive quality edge in more advanced products.

Some of this development can build on fundamental and applied research done within the unit, some can be transplanted from other fields, and some bought from suppliers of equipment and materials. Just as in forestry, however, there is a very definite need to plant new seedlings and to develop new and improved species. No one will do all that necessary work for us. It is just as true for the equipment supplier as it is for the paper manufacturer that the short term, marginal improvements usually show a better return on investment than more fundamental approaches. Hence, and correctly so, only a small fraction, if any, of the R & D investments are directed toward more fundamental attacks on our common problems.

The paper industry is responsible for its own future. One very important aspect of that responsibility has been, and should always be, the initiation, guidance, and nursing of fundamental research into areas of interest specific to the paper industry. Cost effectiveness is one good reason for spending, continuously, a fraction of this R & D investment on collective fundamental research.

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Discussion

Discussion following papers given by Prof. Hartler and Dr. Wahren

Dr. J.Mardon, Omni-Continental, Canada

Professor Wahren's talk, as printed, will become a much-quoted secondary source and therefore I think should be as accurate as possible. I would like to correct a few of his mistakes and rectify some of his omissions. There are three headings under which my comments fall.

Firstly, factual: the name of the company in which Borje Wahlström worked when we made the contributions Dr. Wahren alluded to in his text has been corrected in his addendum. It was the joint research company of two newsprint companies, under the direction of Dr. K.C. Logan. I was in charge of paper-making and Wahlström worked for me.

Secondly, omissions: the most important paper on the subject of taper flow distribution, given in Tappi, 1963, has been noted in Dr. Wahren's errata. There is a good description of the development in Truffit's monograph, also referenced by Dr. Wahren, but Truffit's part in the original team working on this problem has been overlooked. Nor was it mentioned that the same monograph, as its acknowledgement shows, was one of the products of many years' co-operation between several people.

There is also a serious omission on the subject of table roll drainage. Sir G.I. Taylor's paper of 1958[1], in which he propounds his mixing theory and derives his expression for the maximum developed suction ($1/2\ \rho V^2$), has not been referenced. This same important paper also contains the theory of foils. The important paper in Papper och Trä[2], to which Sir G.I. Taylor wrote a long foreword and which he carefully reviewed, is likewise not mentioned. This same paper gives an experimental result more in agreement with Sir G.I. Taylor's theory than any other had shown until then.

When discussing the question of perforated headbox rolls, Dr. Wahren has omitted any discussion of the wake effect, which must be the most serious problem in modern headbox performance.

Lastly amongst his omissions, Dr. Wahren has failed to give due attention to the paper of Heikki Pellinin where the theory of rewetting is very clearly expounded (no ref. available for this).

Finally, I would like to say something about the philosophy of research, and how it actually works.

Several of the people mentioned by Dr. Wahren, namely B. Howe, A.D. Truffit, G. Gavelin, A.B. Truman, P.B. Wahlström, Sir G.I. Taylor and myself, were, and to some extent still are, in contact with one another and with others active in developments not considered in the paper. Anglo Paper Products was in fact the start of an invisible college rather like that of the nineteenth century inventors or the sixteenth century sailors, that endures to this day. It succeeded so well because Dr. Logan had the talent of hiring outstanding people and of leaving them alone, however much they disagreed, to get on with the job. Dr. Wahren does allude to the importance of fighting an idea through to its acceptance. The importance of this has already been referred to here, and undoubtedly will be again, but I wonder how many people really know what it means. In the Great Hall of Kings' College hangs a portrait of Sir Francis Walsingham, Drake's letter to whom after the assault on Cadiz might well be used as a lesson on this.

Lastly, Mr. Chairman, I would like to suggest that, following this conference, a study be made of the history of the Inverform development. R.J. Thomas is already dead, and I think the least that should be done is to give him some posthumous award. Fortunately George Curry and Brian Attwood are still alive, so first hand evidence is available for such a work. Thank you.

Dr. D. Wahren, IPC, USA

Thank you Dr. Mardon. I have no criticism of your history, but would like to say in my defence, that I had no intention in my paper of trying to be complete. Some 500 of the references I found I simply discarded, either because they were not in the few fields I decided to look at, or because they were not firsts. I keep 60 or 70 references in my files on pressing, just to keep up to date. These I have not quoted because they were not part of the main development of the subject. My paper is intentionally very incomplete. But I agree with you entirely that the people responsible for developments, such as the Inverform, must record what actually happened. In preparing my paper I was very suspicious of company records. May I reiterate Dr. Mardon's suggestion that somebody write the history of the Inverform development.

Dr. H.F. Rance, Chairman.

Thank you both. I fancy there is a challenge there to Brian Attwood.

Professor R. Kerekes, Paprican, Canada.

In addition to presenting new information and reviewing old, these symposia can serve a useful purpose in charting avenues for future research. Could each of the authors please cite a few areas where they feel a need for knowledge exists.

Dr. D. Wahren.

If I could give you a really hot tip, I wouldn't. However, what happens to gaseous phases present before the nip? Most must be expelled on the way in, but some must remain to be dissolved under the elevated pressure. Similarly, gases in solution beforehand must to some extent be given off when pressure is released. Then again, what happens to the stratification that one knows must exist, of fibres, water, air and felt, before the nip? This is one of the areas I have been studying, and it really doesn't seem that the system is always stratified. I would very much like to see someone do some really clever analysis of this. If we assume, with Alfred Nissan in 1954, that there are really only water and fibres in the press nip, then we can give up doing any more research on wet pressing.

Dr. H.F. Rance.

I don't know whether that's a hot tip or a challenge.

Dr. A. Ibrahim, AccuRay, USA.

Dr. Wahren's paper about some of the fundamental research that has lead to breakthroughs in the industry interested me greatly. In my experience though, it seems that, often, improvements intended for use on high speed machines are used indiscriminately on low speed machines also, to their detriment. I would appreciate Dr. Wahren's views on this.

Dr. D. Wahren.

Looking at this problem in the terms of set theory, with the need for knowledge constituting the universal set, the background, then existing applications and existing knowledge form overlapping, but not identical sets. Our existing knowledge does not always overlap with our application, and so we have a need for knowledge which does not call for further research, but more probably for education.

Dr. N.K. Bridge, PIRA, UK

The objective of this second session was, I believe, to illustrate the value of "fundamental" (Mr. Place's extrinsic) research, and so perhaps draw conclusions about how to select and manage good projects.

I think I have identified three criteria which are important in deciding which fundamental research is likely to be useful, and I would like to hear the views of the speakers.

Firstly, fundamental research must be clearly directed towards a particular need.

Secondly, we need as much as possible, since there will always be only a small proportion that is useful.

Thirdly, and perhaps most importantly, only the very best people should be entrusted to do it.

This afternoon's speakers have demonstrated how useful some fundamental research has been, but we are all aware of how much goes on that is less valuable.

Dr. D. Wahren.

Of course you are right, though I believe there is still hope. My philosophy is that it would be entirely wrong for me, even if I "know" which experiments to perform and how, to give anything but general guidance. We must of course arrange to have the best brains working on the problem, but most importantly, we must arrange that they are really aware of the needs of the industry. Only by such awareness on the part of the research staff shall we reap rewards from our fundamental research effort.

Professor N. Hartler, RIT, Sweden

To guard against excessive, useless fundamental research, I agree that we must make use of the best brains available. However, it can still happen, despite all our efforts, that the final results are of no particular use. When this happens, we must remember that though there may be no immediate application, our work may well be valuable in the future. In this way, I believe a very large proportion of fundamental research eventually turns out to be useful.

Dr. H.F. Rance.

From the chair, I would like to add that it seems to me that a lot of apparently useless fundamental research adds significantly to our pool of knowledge.

Dr. E.Bohmer, The Norwegian Pulp and Paper Research Institute

On the question of semantics, Mr. Chairman, I would like to say that we all heard Mr. Place describe how there is no point in discussing the terms 'fundamental' and 'applied' research. It seems to me that this afternoon's speakers have amply demonstrated his point.

According to the definition of the American Research Council, I don't think anything that has been discussed this afternoon properly belongs to the field of 'fundamental' research. Consider, as an example, the question of the filtration process on the paper machine. The goal of this research was the improvement of drainage and it was successful. But it could only have been truly fundamental, as Sir G.I. Taylor's work was, if it had been presented as a general theory covering the distribution of liquid films on rotating surfaces.

This is why I think the terms `extrinsic' and `intrinsic' to be so much more appropriate.

Professor B. Steenberg, RIT, Sweden

I want to take issue with Dr. Bridge. I don't believe that more research is better on the assumption that statistically one day we must get better results. My reason for saying this is that, as we heard in the first paper this morning, research runs in fashions. If research activities were independently selected then Dr. Bridge would be correct, but in practice the research community works in Markov chains, which frequently do not follow useful paths.