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SOME DESIGN CONSIDERATIONS FOR SPIRAL SEPARATORS

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ABSTRACT

There are a number of design considerations which influence the selection of a suitable pitch and trough shape for a new spiral separator. The separation requirements impose certain constraints on the total design envelope and mutual interaction between some of the requirements and the conflict between metallurgy and materials handling requirements often defines a narrow range of permissible geometries.

Capacity requirements determine the diameter of a spiral trough but fundamental fluid dynamic considerations play a major role in the selection of pitch and trough shape and the paper considers some of the issues in detail. Where the dynamics of the separation lead to excessive accumulation of solids at high slurry densities, various types of flow deflectors have been adopted either to restore fluidity to the material or to assist in securing a better quality of product.

Apart from the trough, the design of suitable ancillaries such as feed boxes, auxiliary splitters and product collection facilities can exert a significant influence on both the operation of the spiral and the quality of separation achieved. These features are discussed in the paper and illustrated with examples.

Keywords
Design, diameter, pitch, spirals, splitters, trough shape.

INTRODUCTION

Spiral separators have evolved over the past half century from being all purpose, generically designed separators to their present status as sophisticated devices with a high level of design optimisation. Specialised versions have been developed for different types of feed material and duty and many of the ancillaries such as distributors, feed boxes, splitters and product collectors have been redesigned in recent years to improve performance and reduce running costs. A substantial body of work has been published over the past decade[1-13] and the object of the present contribution is to review overall progress in the design area and to examine certain critical developments in detail.

In order to place the major design features in perspective, the first portion of the paper reviews a conceptual model of spiral performance and the design process. Later sections focus on the design of individual features and ancillaries and consider their function in relation to the model.

Spiral separation

The general flow pattern on a spiral can be deduced from basic considerations of fluid dynamics. It consists of a primary (down trough) flow component with a secondary (transverse) circulation superimposed. The secondary flow arises from the greater frictional retardation on the lowermost layers of the primary flow compared with the upper layers and consists of an outward flow in the upper region and an inward flow in the lower region, the terms inward and outward being defined as motion towards or away from the spiral centre column, respectively (Fig.1).

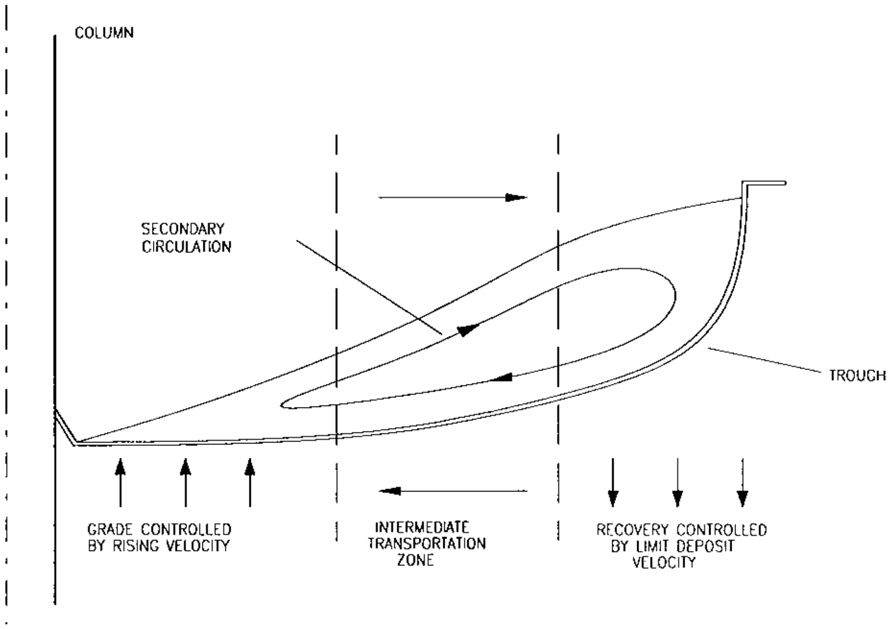


Fig.1 The separation mechanism.

In analysing the separation mechanism, the spiral trough is conceptually divided into two main zones separated by a transition region, all three areas exhibiting different aspects of the fluid flow. The behaviour in the inner (near column) zone is dictated by the creation of a slow moving bed of particles overlaid by a free motion region controlled by the secondary circulation. The rising component of this flow imposes a limit on the size of particle that can just remain in this region and particles finer than this cut size are lifted into the upper levels of the flow and move back into the transportation zone. At any given size, lower density particles are more likely to be lifted than higher density ones, so this cut size exerts a major influence on concentrate grade.

The outer portion of the trough may be considered to constitute a recovery zone, because particles must settle into the lower levels in order to be transported inwards towards the concentrate zone. There is a lower size limit or cut size that can just settle out and this size is dictated by the deposition velocity under the prevailing conditions. Behaviour in this zone, therefore, is regulated by the primary velocity component and will control the quantity and initial composition of material recovered for subsequent further processing in the inner zone.

The intermediate transportation zone normally exhibits a free motion region above a bed region that is relatively less concentrated and more mobile than that in the inner zone: it exerts an influence upon the separation mechanism in approximate proportion to the depth of the bed. Under normal conditions the depth of the bed is not excessive and the majority of the material within the transitional zone moves with and forms part of the secondary flow, so it may be regarded as part of the inter-zone transportation system rather than as a major factor within the

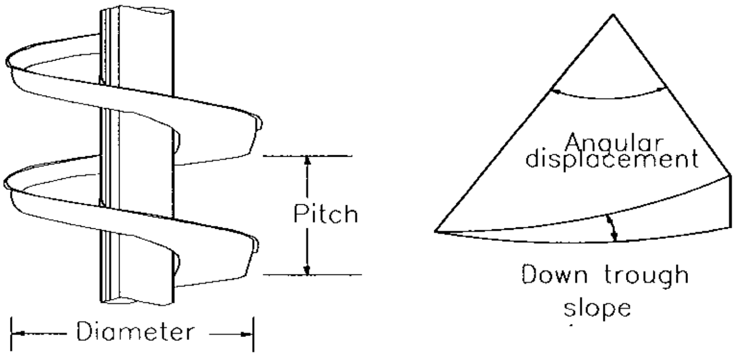


Fig.2 Spiral geometry.

separation. This is not the case if the bed builds up to the point where it occupies the majority of the flow depth in the central region of the trough. The nature of the flow changes visibly, with a marked reduction in the secondary circulation and additional forces come into play within the bed, converting the separation into a predominantly bed-controlled mechanism more akin to a sluice than a normal spiral. This latter type of operation is not considered either typical or desirable in most cases, but in a minority of cleaner type applications where the feed is of high grade it has been found to offer superior metallurgy. This is usually at the expense of materials handling, with sanding conditions never far away.[7] A summary of the forces that influence the behaviour on spiral troughs was provided by Sivamohan[1].

In operation, the performance of all types of spiral is affected by the volume and density of the slurry fed to the trough[5]. At very low feed rates, the solids settle out too readily and the separation is ineffective because the inter-zonal transportation mechanism is retarded by the dominance of frictional effects. As the feed rate is increased, the separation mechanism becomes increasingly effective until a stage is reached where the trough is optimally loaded. Beyond this point, further increases in feed rate result in the additional volume being centrifuged directly to the outer zone and the vortex effect in this region becomes progressively more vigerous, effectively locking up much of the additional solids in suspension. The overall circulation across the trough also increases in strength, which increases the lifting effect in the inner zone. The overall pattern of behaviour dictated by the volumetric feed rate is therefore poor selectivity and high recovery at low feed rates, modifying progressively with increasing selectivity and decreasing recovery as the feed rate is increased. The effect on the recovery has been found to be effectively linear with the feed rate expressed in t/h of dry solids[5,10] and the separation efficiency normally rises very rapidly to a maximum value at low feed rates and therafter also falls off linearly with feed rate (Fig.3).

The design process

The design process consists of a number of interactive stages and often proceeds in a non-standard manner, but for purposes of discussion it is possible to relate the main activities to one another in a reasonably systematic manner. The scale issue is usually considered first, followed by the volute shape and the associated sanding analysis: when these aspects are finalised, a detailed examination of the materials handling requirements leads into the design of the ancillary features. Each of these stages will now be discussed, though commercial considerations will restrict the amount of detail included.

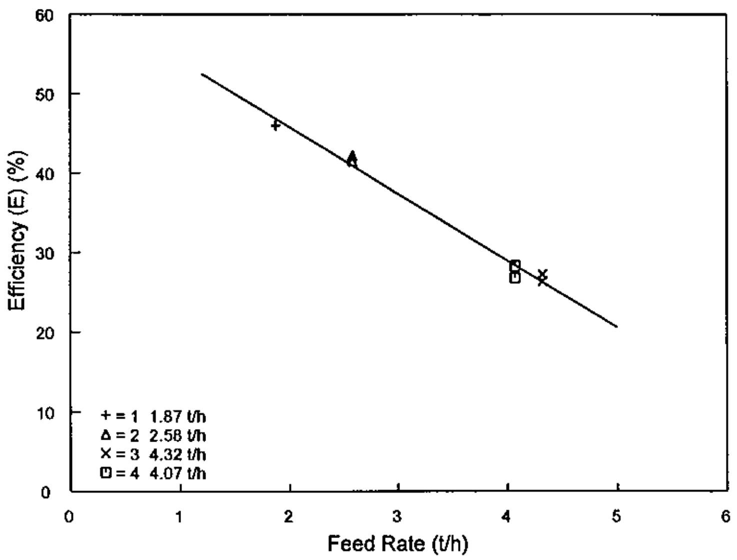


Fig.3 Effect of feed rate on efficiency of spiral separation.

Pitch and diameter

The activities involved can be represented in the form of a flow chart (Fig.4). Once the required separation size and capacity have been chosen, the diameter of the spiral can be specified and the pitch can then be estimated via a route that makes use of limit deposit velocities^7 to estimate the down trough slopes and hence the pitch required.

The capacity of a spiral is related to the trough area for a given separation size range and decreases with particle size. It follows that a successful scaling up operation should achieve equivalent metallurgy at a capacity increase at least equal to, but preferably greater than the ratio of the areas would indicate. In Fig.5, the peak efficiencies for two mineral spirals of radius 32.5 cm and 46.0 cm respectively (area ratio 2:1) have been plotted against feed rate and the same type of linear relationship shown in Fig.3 was found. It can be seen that at an equivalent efficiency of 75%, with minor extrapolation of the performance lines the capacity ratio is estimated as 2.4 and this scale up was judged to be very successful.

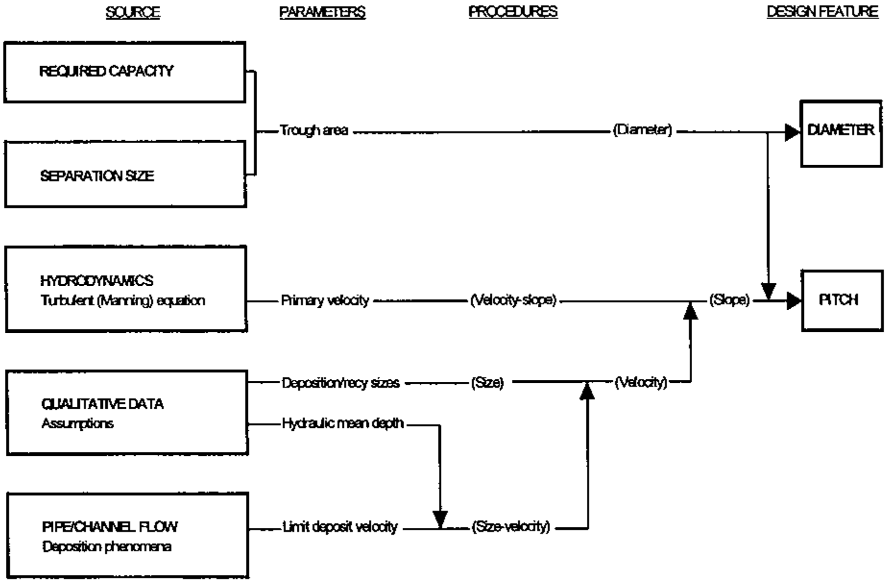


Fig.4 The design process: pitch and diameter.

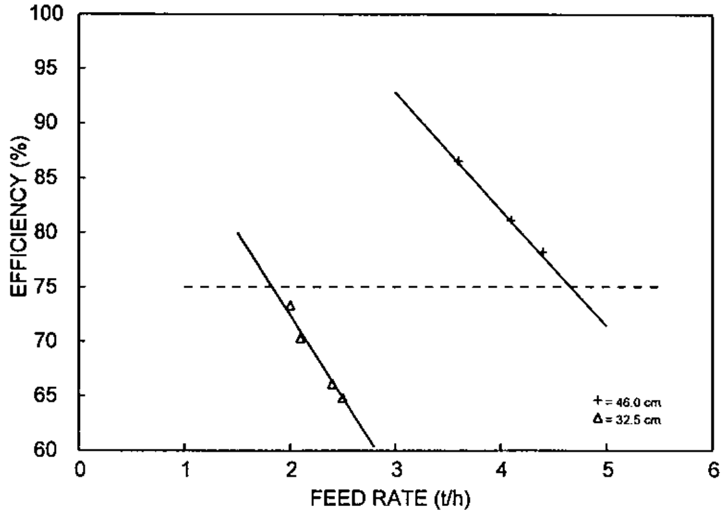


Fig.5 Scale up performance for mineral spirals.

In Fig.6, a similar scale up study for coal spirals is shown and an efficiency level of 50% was employed in the comparison because of the limited data available for the smaller spiral. The capacity ratio was just over 2 for an area ratio of 2 and this was also considered a success: the more difficult separation conditions with lower density material such as coal make scale-up a greater problem than with mineral spirals.

Volute shape, profile changes and trough length

The choice of volute shape and any systematic change in the profile down the trough dictate a sequence of design evaluations that can be approximated by the flow chart shown in Fig.7. In individual cases the sequence may vary from the pattern shown but at some stage or another most of the activities represented in the flow chart will be carried out. The issue of trough length was considered in a recent paper[11] and will not be discussed in detail here: it was concluded that the current five to six turn designs are appropriate for the majority of applications.

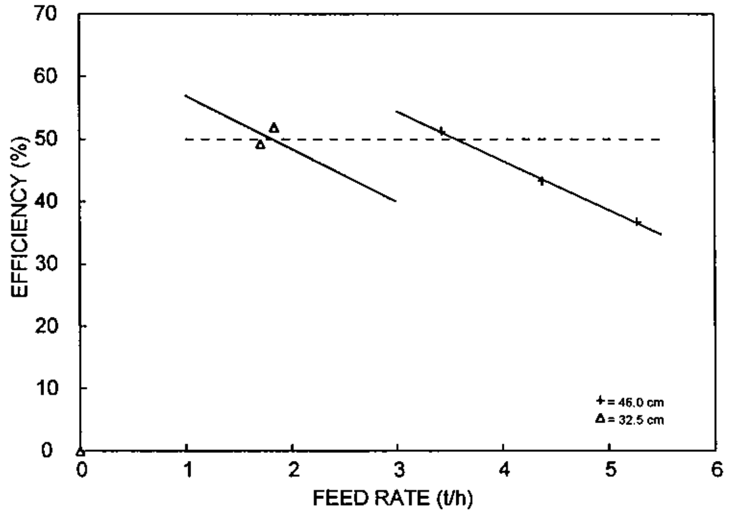


Fig.6 Scale up performance for coal spirals.

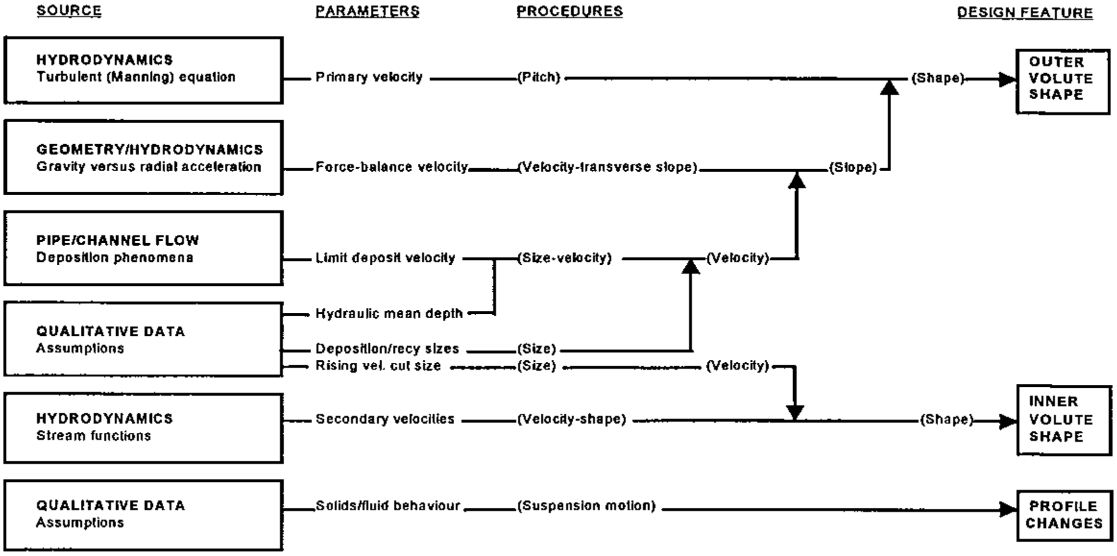


Fig.7 The design process: volute shape and profile changes.

If a variation in profile is introduced, it proceeds according to one of three patented systems (Fig.8) whereby either the transverse trough slope changes, the point of maximum downward displacement moves laterally, or the diameter and shape of the spiral changes. These features are introduced to promote lateral particle motion in the desired directions once the preliminary settling operation has taken place. The shape of the trough has a profound effect on the nature of the fluid flow phenomena generated as the slurry flows down the spiral and hence on the separation performance: for a given pitch, one shape will produce excellent metallurgy but poor materials handling while another shape may excel at transporting the solids but perform badly in other respects.

In extreme cases, poor materials handling will deteriorate into sanding or beaching, where a stationary bed of solids forms on the trough and spreads until the trough is blocked. This condition is often only slightly removed in design terms from excellent metallurgical performance, so a system of analysis was developed to identify the extent to which a given trough shape and pitch approached sanding behaviour. The procedures involved in the sanding analysis are shown in Fig.9 in schematic form.

The basis of the sanding assessment[7] is to select two limiting sizes of particle that define the onset and completion of sanding when they deposit out, these sizes being conventionally set at 100μm and 1000μm. If the local primary flow is greater than both these deposition velocities, then no sanding will occur. If the velocity is between the limits, a transition to sanding behaviour is in progress, and if the velocity is less than both deposition velocities the spiral will sand up in the area under consideration. An example is shown in Fig.10, where the profile and sanding plot is illustrated for a heavy mineral spiral.

The sanding analysis is displayed as a plot of primary velocity against trough radius with the flow velocities on the vertical axis and spiral radius as the horizontal axis. The limiting deposition velocities are shown as horizontal lines and the regions corresponding to no sanding, transitional behaviour, and total sanding are bounded by these lines. It is convenient to show the resultant trough slope as a function of radius on the same diagram so that the area of greatest danger can be identified. The resultant slope is the actual slope experienced by fluid flowing down the volute and is determined by the down trough and transverse slopes: because of the shape of the trough, it normally reaches a minimum in proximity to the outer wall and this is the area of greatest danger for sanding.

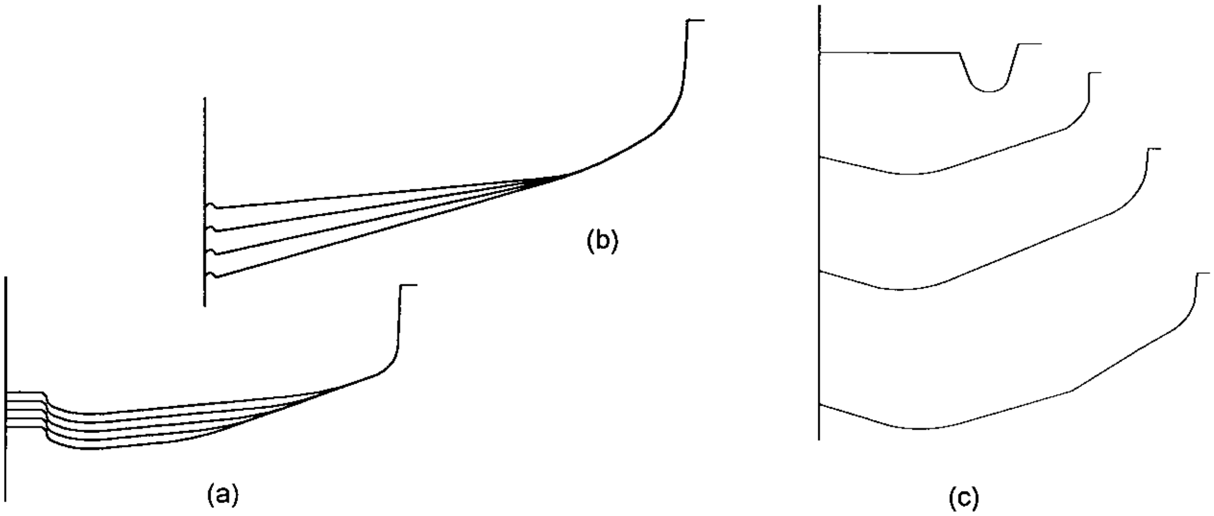


Fig.8 Trough profile variations: (a) varying point of maximum displacement; (b) varying transverse slope; (c) varying diameter and shape.

The sanding example illustrated below relates to a heavy mineral spiral that operates on the extreme edge of the good metallurgy/bad materials handling interface: in testwork, the unit frequently surpasses the performance of competing designs but exhibits sluggish flow behaviour and occasionally sands up on the lower turns.

The designed profile for the final turn is shown in Fig.10a and the sanding assessment in Fig.10b: the limits defining sanding behaviour have been specified as 1000 microns for the onset and 100 microns for completion shown on the figure as two horizontal lines which correspond to the deposition velocities for these sizes. The predicted primary flow velocities are the upper of the two curves (solid line) and the resultant down trough slope has been plotted in degrees (dashed line) using the velocity axis. Correct behaviour is normally evidenced by sanding or near sanding in the innermost region and then a rising curve through the transitional region at larger radii, culminating in a steep rise to no sanding before the outer wall area where the minimum slope radius is usually located.

On examining the sanding assessment, it can be seen that the minimum resultant slope is reached at a radius of about 20 cm in the centre of the trough rather than in the expected location: this corresponds with a sharp dip in the primary velocity profile and it is clear that sluggish flow can be anticipated with this design.

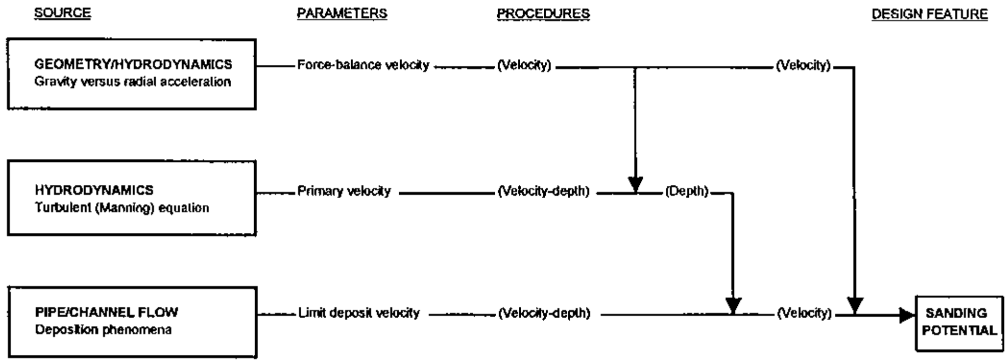
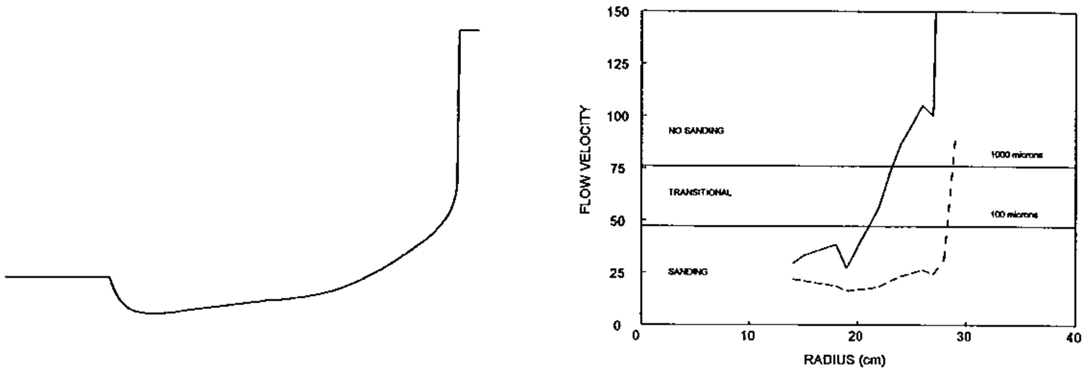


Fig.9 The design process: sanding analysis.



(a) (b)

Fig.10 Sanding analysis for a heavy mineral spiral: (a) trough; (b) analysis..

Ancillary features

The design or selection of the various ancillary features is often dictated by special considerations, but a generalised representation of the decisions involved is possible (Fig.11) and some of the special considerations are briefly discussed below.

Feed boxes

Most of the design features of spiral ancillaries can interpreted in terms of the separation concepts described previously. The slurry should be introduced to the trough in a direction parallel to the walls of the trough and in a manner calculated to lead to the creation of the equilibrium flow pattern as rapidly as possible without undue splash or surging, with the solids uniformly distributed within the slurry. In order to achieve this, the feed box must incorporate the features necessary to dissipate excess fluid head and mix the slurry while modifying the direction of flow through angles of up to 90° (in the case of top fed boxes) and must provide adequate protection against the severe wear characteristics of some slurries. Modular feed boxes (Fig.12) provide these facilities and are also capable of being installed on either right handed or left handed troughs.

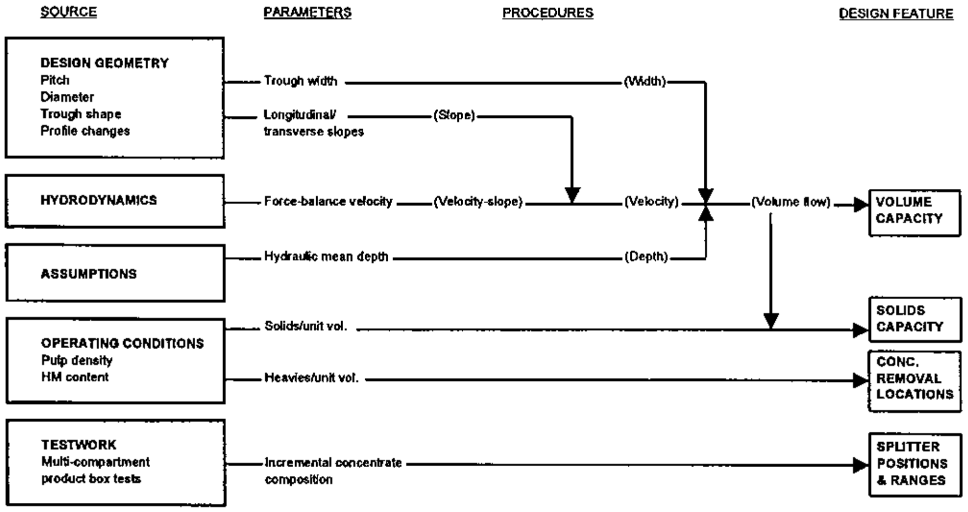


Fig.11 Design and selection of spiral ancillaries.

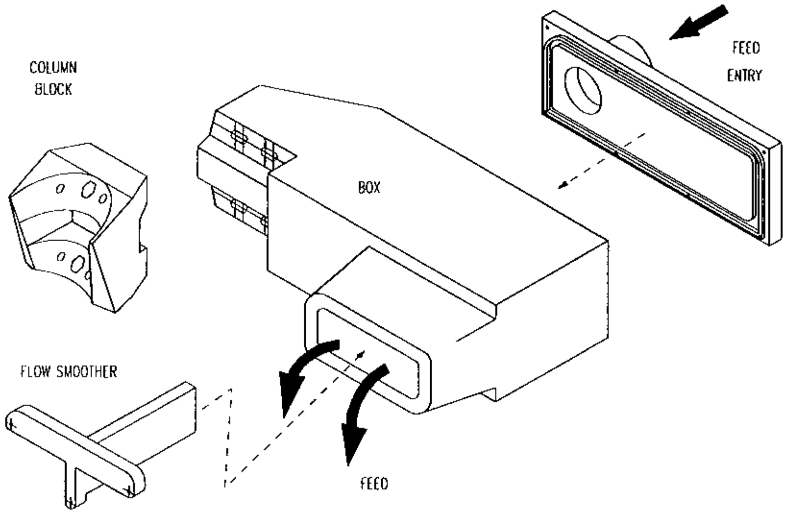
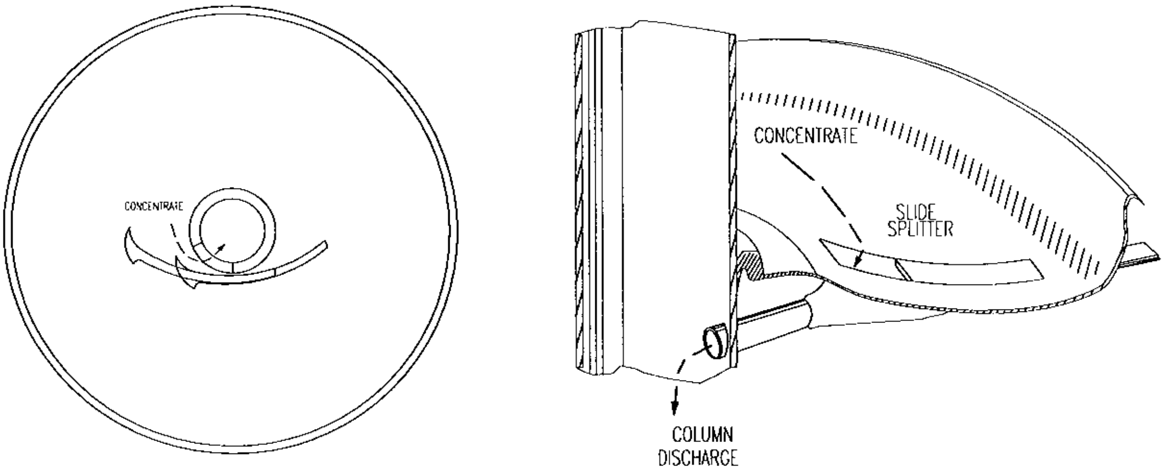


Fig.12 Modular feed box.

Although anecdotal evidence exists to the effect that entry conditions can affect separation results, no documented evidence has been recorded. In deference to this opinion, however, a wide variety of feed geometries are in evidence in commercially available spirals.

Auxiliary splitters and repulpers

Once the separation is in progress and material begins to accumulate to form a bed in the inner zone, the fluidity of the bed progressively diminishes and the rate of flow slows down. With high concentrations of heavy minerals in the feed, the bed can eventually become completely static and it then extends further and further into the working region of the trough, effectively modifying the profile. This can eventually prevent any further separation from occurring, so high grade spirals are normally equipped with one or more auxiliary splitters to facilitate removal of separated solids before they lose too much fluidity. There are several different possible designs available, including small finger splitters, banana splitters and slide splitters (Fig.13a-b).



(a)

(b)

Fig.13 Types of auxiliary splitter: (a) banana, (b) Slide.

At this stage of the separation, the bulk of the fluid entering with the feed solids has been centrifuged to the outer zone and, particularly on wash-waterless spirals, it is frequently beneficial to redistribute some of the slurry from the outer zone across the inner zone by means of a repulping device. This restores lost fluidity to the material in the inner region and also provides a second chance at separation for misplaced solids from the outer zone.[11] There is a choice of repulper designs available, providing different degrees of severity in the repulping action: one type of repulper design is illustrated in Fig.14. Where the fluid fan created by the repulper is exposed to wind effects, it can give rise to spray and spillage and a repulper lid is then fitted to the trough to protect the flow.

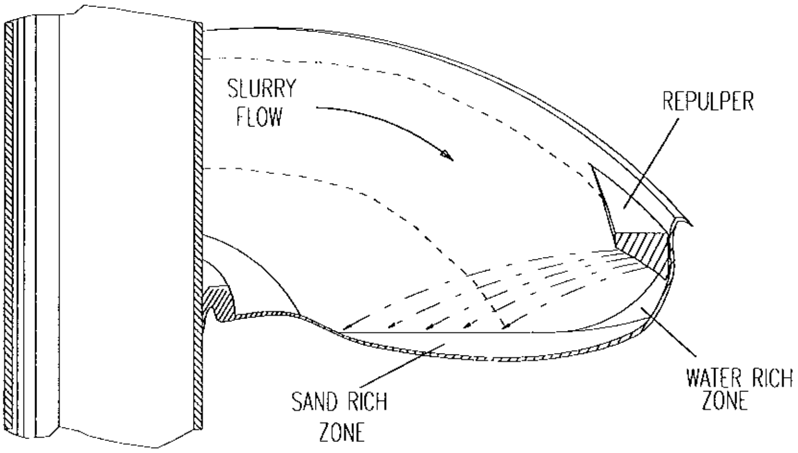


Fig.14 Repulper action.

If there are significant amounts of fine heavy mineral present in the feed or if the fine mineral is of high specific gravity relative to the design specification (e.g. pyrite or magnetite occurring in coals), a problem similar to that caused by excessive bed development can arise with the fine mineral depositing along the inner wetted limit of the trough and eventually drying out. This effectively modifies the trough profile in the inner zone and adversely affects the separation performance: it has been found beneficial to design the trough so that there is an inner wall rather than a flat surface for the flow to terminate on and to ensure a minimum flow depth in this region under all feed conditions. Where necessary, existing designs have been modified by providing a flow termination surface in the form of a beading superimposed on the trough surface. On some models of coal spiral designed to operate in low to medium ash regimes, additional finger splitters are provided on the upper turns of the spiral to permit early removal of pyrite or magnetite before it has a chance to accumulate on the trough surface.

Main splitters

It is possible to employ either slide or pivoting blade splitters to provide the main flow divisions at the end of the trough and the majority of the early Wright spirals utilised twin slide splitters in this role. However, the nature of the splitter directs the concentrate flow towards the column and product removal must therefore be achieved either via a channel adjacent to the column or internally through the column. If there are also auxiliary splitters further up the trough with tthe same requirements, this can lead to unnecessary complications in the materials handling requirements. In consequence, the main splitters on spirals are normally of the pivoting blade type, with the pivot axis substantially vertical to the trough surface to minimise the distortion introduced into the trough surface and to provide an adequate seal between the bottom of the splitter blade and the swept arc on the trough surface.

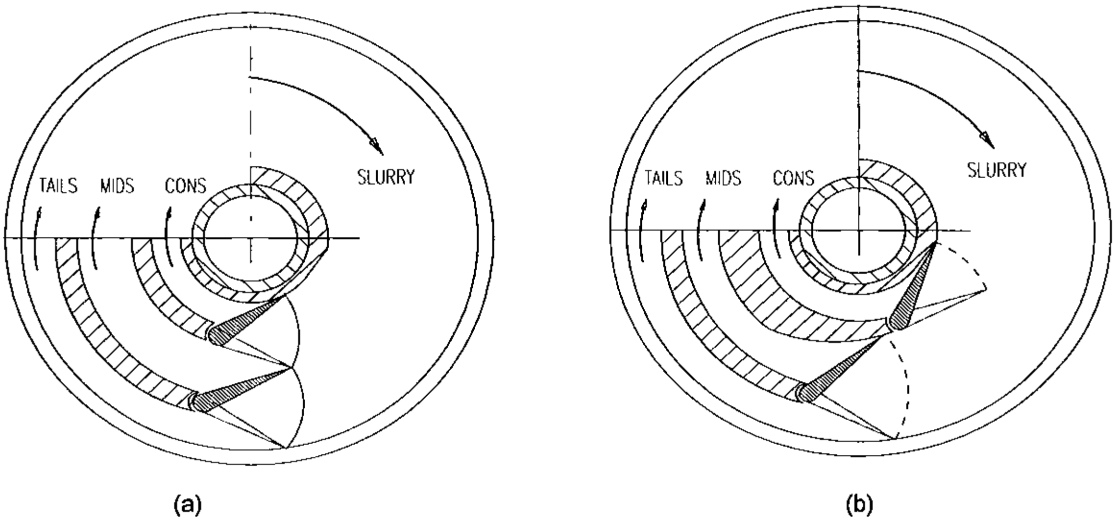


Fig.15 Types of main splitter: (a) parallel; (b) offset.

The splitters may be located in parallel or offset to permit the total elimination of either middlings or concentrate products (Fig.15a-b). There has been controversy regarding the merits of the offset splitters, the main objection being the disturbance to the separation performance of the second splitter resulting from the wave effect created by the leading splitter. This issue has been investigated by comparing the performance of three models of spiral, all of them based on the same trough profiles but incorporating different combinations of splitters (Table 1).

Unfortunately, the tests were not conducted for the purpose of comparing splitter types and the parallel and offset splitter versions of the same spiral (A,C in Table 1) were tested on different occasions against a third spiral (B in Table 1), so a two stage evaluation is necessary. In Fig.16, spirals A and B have been compared by plotting efficiency against cumulative mass take for tests conducted on a mineral sand feed assaying about 5% heavy mineral. These two spirals had the same main splitter configuration and the only difference was the introduction of an additional splitter on the second turn for spiral B: this had the effect of reducing the efficiency by about 1.5% on average.

Table 1 Test spirals

Spiral	Auxiliary splitters			Main splitters		
Type	Number	Type	Location	Number	Type	Location
A	1	Slide	Turn 4.3	2	Pivot	Parallel
B	2	Slide	Turns 2&4	2	Pivot	Parallel
C	1	Slide	Turn 4.3	2	Pivot	Offset

In Fig.17, spirals B and C have been compared in a similar manner by plotting test results obtained on two other mineral sand feeds, both assaying about 5% heavy mineral but neither from the same source as the first sample. The result was the same in both cases with the parallel splitter showing superior performance by about 4-5% efficiency in one case and about 2% in the other for an average difference of about 3%. The difference between spirals A and C, i.e. the effect of offsetting the splitters, could therefore be of the order of 5% efficiency at peak though this would vary with the material. Although this sounds to be a significant penalty, in practice in a multi-stage circuit the lost efficiency can be regained by employing a slightly greater mass take for spiral C and compensating for any grade/recovery changes by adjustments within other stages of the circuit.

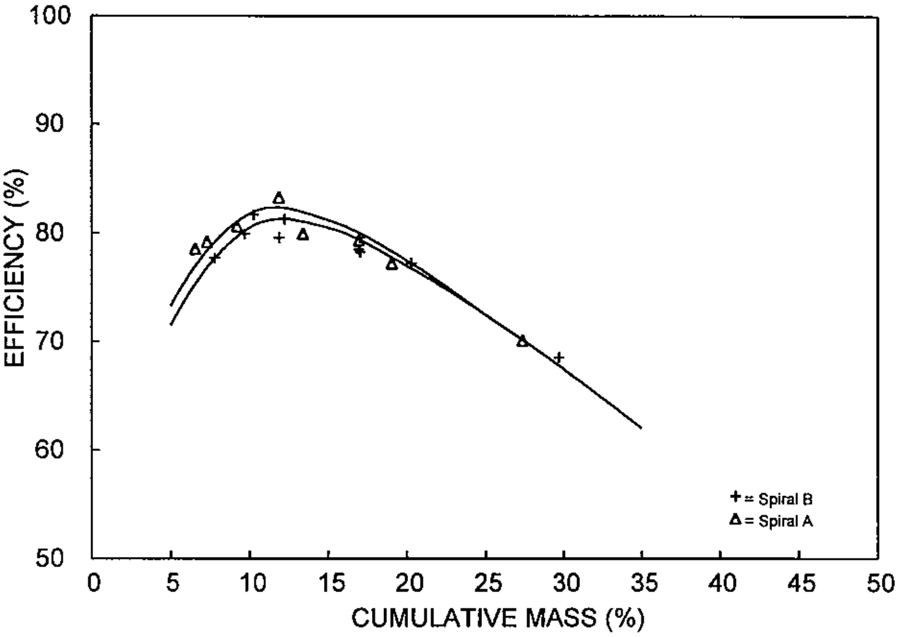


Fig.16 Effect of splitter numbers and location: spirals A,B.

The splitters may be located on or embedded in the trough surface or they may be positioned exterior to the trough, the former being the more common approach where there are no unusual circumstances. Exterior splitters can be mounted either with a vertically orientated shaft and the blades contacting the end of the trough or with the splitter blades located beneath the trough and rotating on a horizontal shaft.

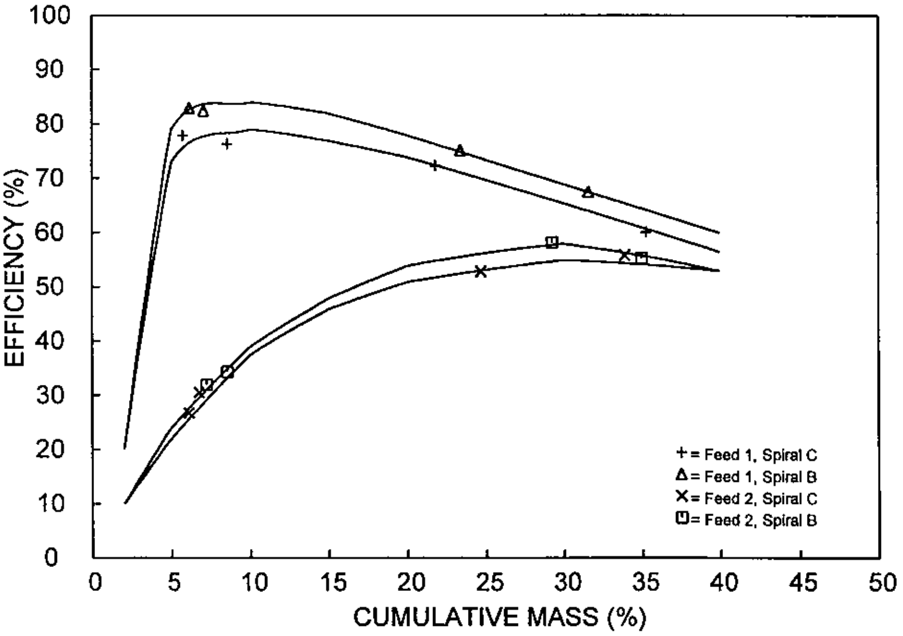


Fig.17 Effect of splitter types: spirals B,C on two different feeds.

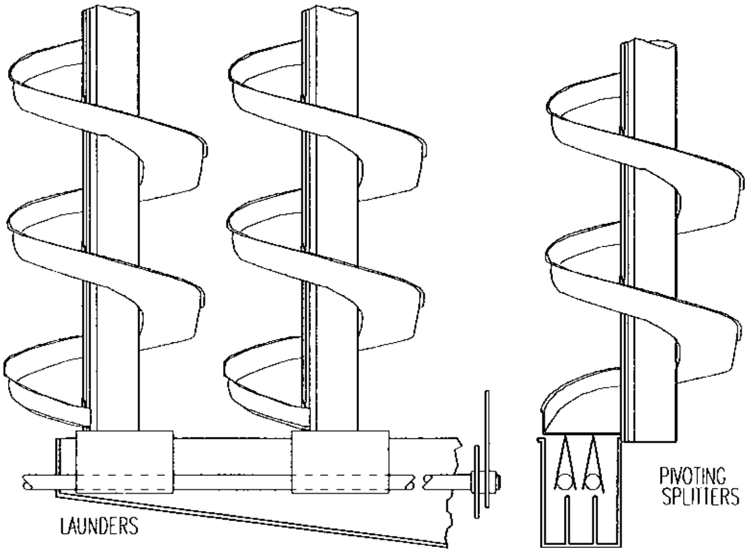


Fig.18 Horizontal axis main splitters.

An example of the latter system is shown in Fig.18: this type of splitter is suited to operating environments where there are problem materials such as clay or adhesive slime or excessive amounts of weed. With the standard types of pivoting splitter, these contaminants can accumulate on the trough in the vicinity of the splitters until a total flow blockage is created, though it is possible to alleviate the problem with special type of repulpers and flow diverters.

The introduction of multiple start spirals with several troughs mounted on a common column created a control requirement for identical splitter positioning, so linked or ganged splitters were introduced with the blades attached to a common shaft (Fig.19). An unavoidable consequence of this was the creation of greater distortion in the trough surface in the splitter region due to the axis of the common shaft and the swept arcs being aligned at an angle to the trough surface, which does disturb the flow to some extent: in instances where this is likely to introduce unacceptable penalties the splitters are relocated in the product receiver rather than on the trough itself.

Other ancillaries

The final component needed to complete a working assembly for a spiral is some form of products receiver to handle the product flows from the auxiliary and main splitters: there are almost as many designs of product receiver as there are spiral models on the market, varying from simple pipe mouldings attached to the end of the trough to elaborate multi-component assemblies that can accommodate up to five starts. Although critical to satisfactory operation in terms of wear resistance, avoidance of splashing and suitable materials handling characteristics, the design of the products receiver does not affect the metallurgy and will not be considered further.

In addition to the ancillaries associated with individual spirals, the usual plant installation of spirals involves banks of similar units operating in parallel on a common feed: it is then necessary to provide frames to support the spirals, distributors to divide the incoming flow equally between each spiral start, and launders to transport the combined product flows. The external ancillary capable of exerting a major influence on spiral performance is the distributor: the effect of feed rate on the separation has been mentioned in this contribution and has received detailed attention in another recent publication[10] which also included an analysis of distributor requirements.

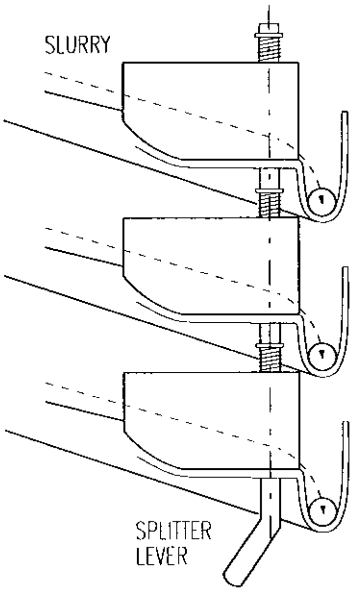


Fig.19 Ganged pivoting splitters.

Future design trends

The spiral has come a long way in the half century since it was invented and the design improvements that have been incorporated in the past decade have resulted in the availability of separators that are optimised for individual applications. The discussion of design procedures highlights the extent to which the adoption and adaptation of fluid dynamic theory has replaced empirical design guides and the general understanding of the forces at work in the separation environment has increased markedly as a result. There is still room for improvement in the accuracy with which the behaviour in modelled and the trend to ever more powerful computational facilities and software[12,13] will provide increasingly sophisticated simulation capabilities. When these are applied in the design area, it will be possible to provide further improvements in performance, though the magnitude of the gains will not be as large as we have become accustomed to in the past.

SUMMARY AND CONCLUSIONS

This contribution has reviewed the current state of the art in spiral design with particular attention to design procedures. A brief overview of the separation mechanism was provided prior to considering the design process, which was analysed as two separate topics covering the major geometric parameters and the trough respectively. Particular attention was paid to the issue of scale up, with examples of the results attained with both mineral and coal spirals. Trough shape was then discussed with a focus on materials handling aspects including an example of a sanding assessment. The various ancillaries needed to complement the trough were then reviewed in the light of the separation mechanism and the role each item has to play in optimising the overall performance. Where feasible, comparative data were included to illustrate the consequences of design decisions. Finally, future trends in design capabilities were discussed and it was concluded that there is still scope for improvement, though the maturity of the technology will make the gains incremental rather than major.

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