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THE NO.4 PICKLE LINE AT BSC EBBW VALE WORKS[1]

by

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SUMMARY

1. **Line Description**

The No. 4 pickle line now being built by Head Wrightson for BSC Ebbw Vale Works is described.

2. **Some Design Aspects**

A discussion of the main factors influencing design of a modern high-speed pickling line is presented.

2.1 Coil Size/Outputs : The relationship between line speeds and acceleration, time required for welding, and coil length is considered. The main factor which determines output and line speeds is the length of coils : large coils are necessary for high outputs.

2.2 Control of Strip Speed and Tension : A certain minimum tension is required for good tracking. Effects such as viscous drag, drag owing to bending of strip around rolls, and friction in undriven rolls cause an increase in strip tension. Acceleration forces can give rise to extremely high tensions and great care is needed in selecting acceleration rates.

2.3 Strip Steering : Steering rolls are placed in critical positions in the line, such as at the ends of the long horizontal runs in the storage loops. A novel type of steering roll is employed.

2.4 Support Structure and Tanks : The Ebbw Vale pickle line is probably unique because it spans a valley between the hot and cold mills. The line and its support structure are carried on a bridge. The interaction of the pickle line structure and the bridge structure is described, together with the method for dealing with thermal expansion.
Structure columns are positioned above bridge columns and the tanks are designed to be self-supporting between these columns.

2.5 Process Section : Choice of acid strengths and temperatures, the use of an entry hot-water tank for preheating, and the method of fume extraction are explained.

1. Line Description

This is a continuous pickle line using hydrochloric acid and is designed to operate at process speeds of up to 305 metres/min (1000 ft/min). The entry section is motored for speeds up to 762 metres/min (2500 ft/min) and the exit section up to 396 metres/min (1300 ft/min).
The strip varies in width from 610 mm (24") to 1320 mm (52") and in thickness from 1.2 mm (.048") to 3.7 mm (.145"), although the shears and edge trimmers are designed to handle strip up to 4.75 mm (.187").
The line layout is shown in Fig. 1.

Coil Loading

Coils are brought to the line with bores horizontal, on walking beam conveyors, each of the two pay-off reels being served by a separate conveyor. The coils are transferred from the conveyors to the reels by hydraulically operated coil carriages fitted with 'U' shaped cradles which are designed to accept the moving conveyor beam in its extended position. The two reels are at different levels, and the vertical disposition of the reels and carriages has been so arranged that for No. 1 Pay-Off Reel the carriage cradle is in the maximum lowered position when taking the coil from the conveyor, and then raises it the level of the reel drums. For No. 2 Pay-Off Reel the carriage cradle is in its maximum raised position, and the coil is hence lowered to bring it in line with the reel drum. This use of the ultimate top and bottom cradle positions obviates the necessity for the operator to set accurately the cradle position for coil loading.

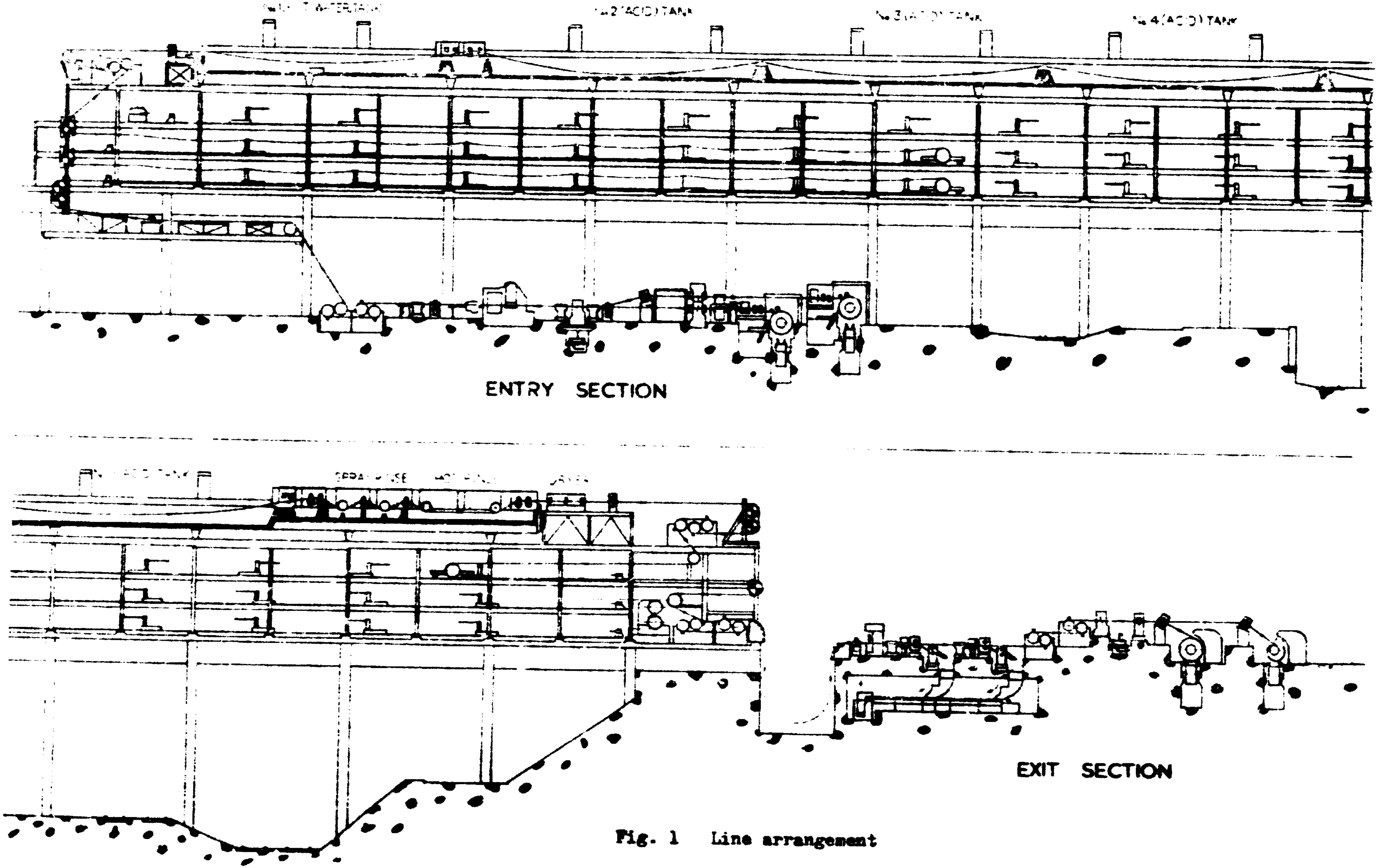


Fig. 1 Line arrangement

Strip Feeding

Each Pay-Off Reel is followed by an Uncoiler Leveller or Flattener equipped with two pairs of pinch rolls and five levelling rolls.

Coil opening and strip feeding is assisted by the use of a coil opening knife situated under each flattener and an undriven snubber or restraining roll acting on the top of the coil, working in conjunction with the uncoiler drive. A separate backed-up breaker roll can be brought into use when the strip has been fed through the flattener to assist in smooth unwinding of the strip and to minimise the effect of "coil breaks" on strip prone to this defect. A secondary effect of the breaker roll is in scale cracking, and each flattener is provided with water sprays on either side of the strip between the first and second pair of pinch rolls to prevent a dust problem. In order to keep the distance between the two pass-lines to a minimum, a double shear is included comprising one up-cut and one down-cut shear. All blades are interchangeable and are mounted in cartridges which can be removed, replaced, and locked in position from the side of the line. Both shears are provided with entry and exit pinch rolls; one roll in each set is driven at threading speed by a D. C. motor, and the shearing cycle is operated by manual control on a start/stop cycle. The table immediately following each shear is arranged for upward pivoting, allowing cut sheets up to 6 ft. long to feed onto roller tables running at right-angles to the line, and discharging sheets into a skip.

Provision is made at the double shear for the removal by hand of small pieces of strip from the leading edge of the strip to check for laminations.

Welding.

A squaring shear is located at the junction of the upper and lower pass-lines. This shear, provided with centring side guides fore and aft, accurately trims and "squares" the lead and tail ends of the strip prior to welding. Scrap pieces fall down either side of the shear into a skip mounted on a hydraulically operated trolley

The welder is a Taylor-Winfield flash butt type, built by A I Welders Ltd of Inverness, with weld scarfer, strip notcher, and entry and exit looping rolls. A pinch roll unit and humping roll are provided after the welder to assist in positioning the tail end of the strip in the welder.

Carry-Over Tables

The gaps between machines are spanned by tables comprising a series of polyurethane-covered undriven rolls. To obviate marking of the strip caused by the strip intermittently contacting closely pitched rolls, the rolls are widely spaced, thus ensuring that all rolls are contacted, and the spaces between are fitted with machined cast-iron plates set below the pass-line.

Loop Storage

The strip travels from the entry section via a 3-roll bridle to the entry storage loop which holds sufficient strip for approximately a two minutes stop of the entry section with the process section operating at full speed.

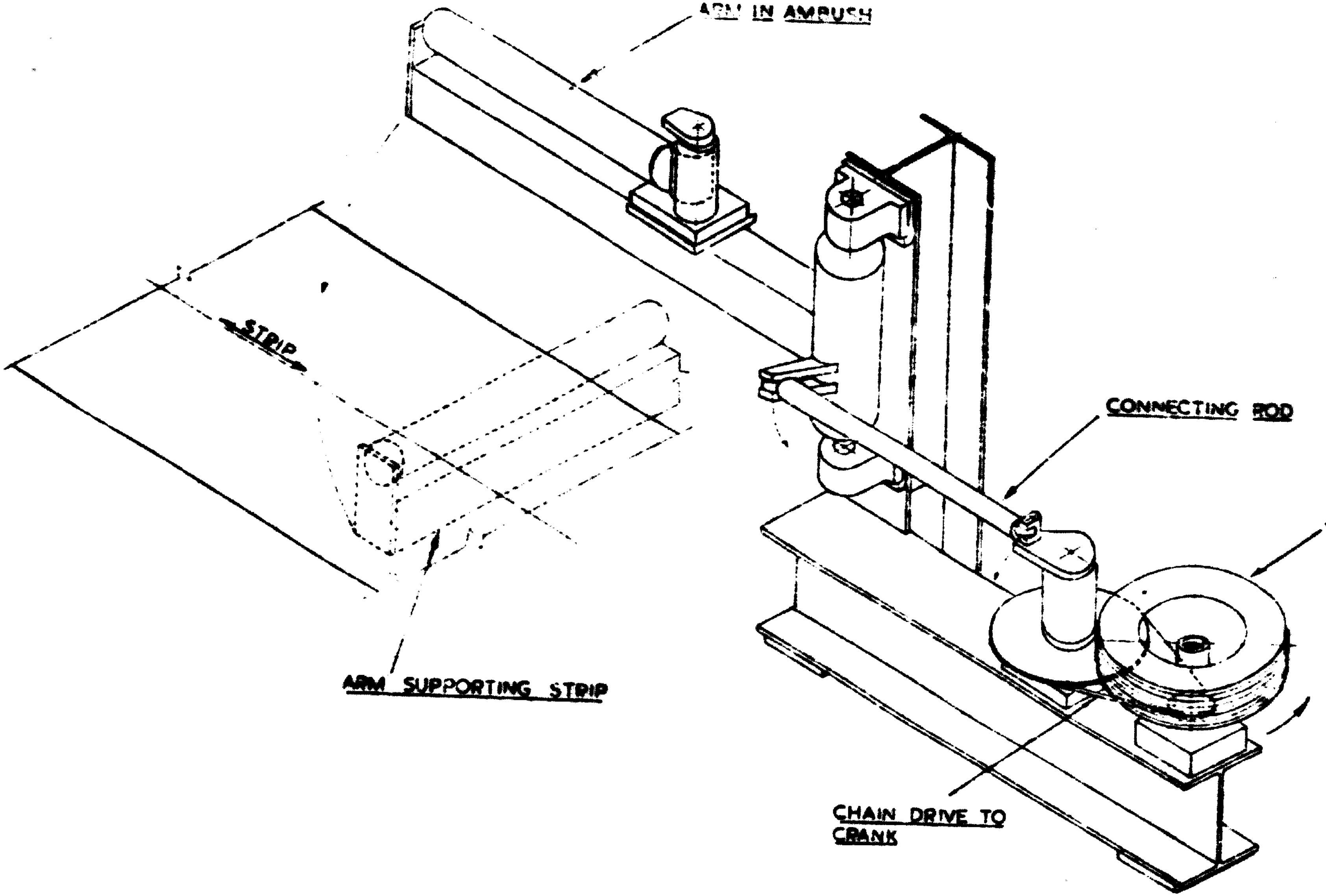


Fig. 2 Loop support arm

Steering rolls are provided going into, between, and leaving the loop. The top strands of strip in the loop are supported on rolls mounted on swinging arms provided with a recently developed retraction mechanism giving a harmonic motion of the arm, the main purpose of which is to eliminate the shock loading previously associated with this type of car-actuated support roll (Fig. 2).

Process Section

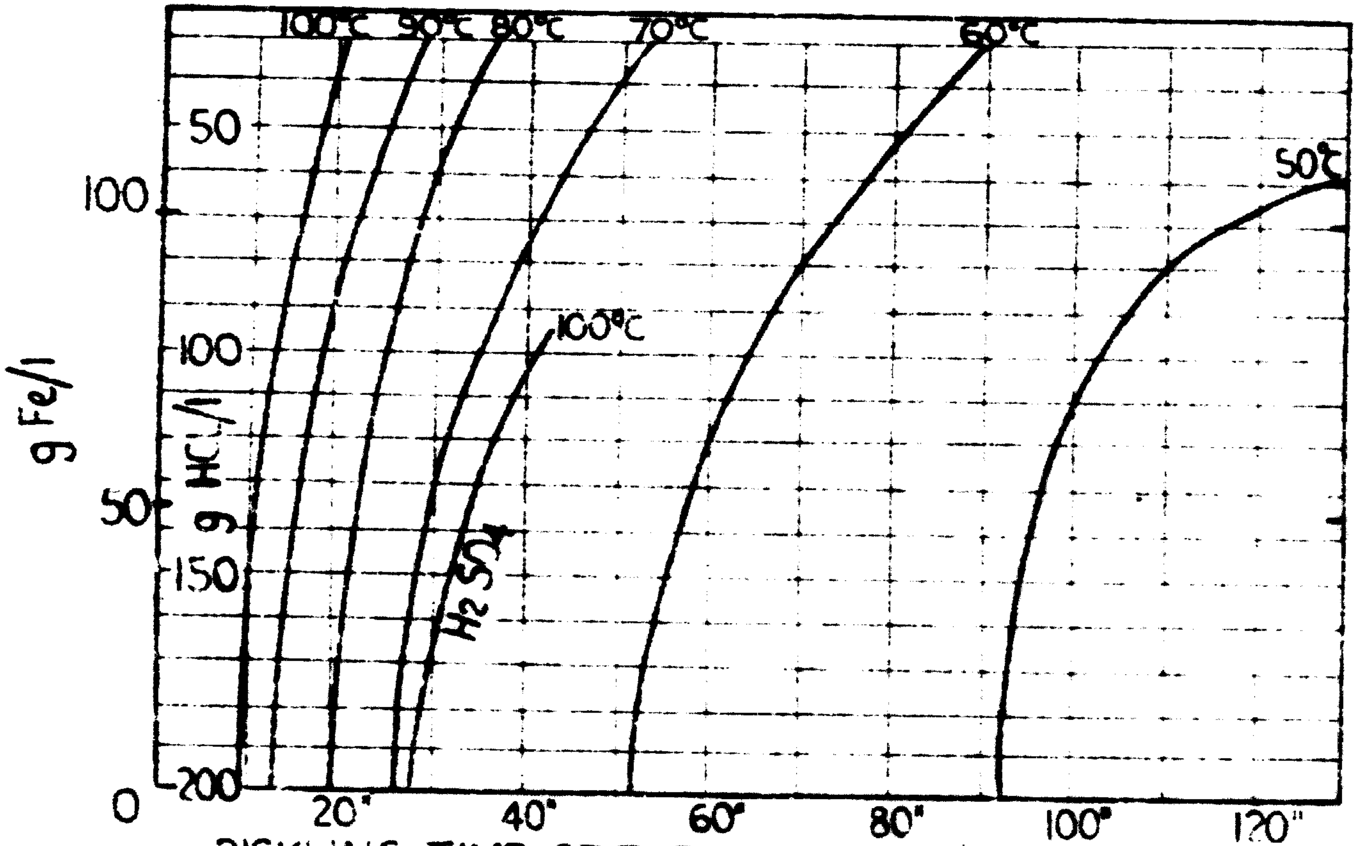
From the entry loop, the strip travels via a bridle followed by a tensiometer roll to the pickle section comprising a hot water pre-heat tank, four acid pickling tanks, primary and secondary spray rinse tanks, and a hot water dip tank.

This process section has been designed to operate on conditions specified by the BSC as given in Fig. 3.

The tanks are mild steel, rubber-lined, and bricked; covers are mild steel, rubber-lined lift-off type, the covers on the pre-heat and acid tanks being provided with side members dipping into water seal troughs along the tank edges, to prevent escape of fume.

Regenerated or fresh acid is fed into No. 4 or No. 5 Tank and flows in contra-direction to the strip over the granite skid caps and taken out at No. 2 Tank. Operation heating is by one Cepic heat exchanger on each acid tank, with direct steam injectors for hot water heating, and for initial and standby heating of the acid tanks.

99°C HOT WATER TANK	93°C HCL 4.8 % F_eCL_2 20.0% PICKLE TANK N°2	93°C HCL 8.9 % F_eCL_2 13.0 % PICKLE TANK N°3	80°C HCL 12.6 % F_eCL_2 8.0% PICKLE TANK N°4	77.8°C HCL 16.0% F_eCL_2 3.0% PICKLE TANK N°5



PICKLING TIME OF THE HYDROCHLORIC ACID AS A FUNCTION OF HCL AND Fe CONCENTRATION BETWEEN 50 - 100°C.

[illegible] Ac. strengths and temperatures

Dragout between the acid and wash sections is controlled by means of 2 sets of wipers positioned above the final granite skid, followed by double wringer rolls. The wiper blades are mounted in a cruciform holder, allowing indexing to the next blade when one is worn. All sets of double wringer rolls, after the pre-heat and acid tanks and after the hot water rinse, are mounted on pivoting arms. In the absence of any powered steering motion this H W patented design allows the roll assembly to align itself with the strip; this applies on the final set of wringer rolls. On the rolls immediately following the pre-heat and acid tanks a hydraulic cylinder controlled by a photo-electric sensor is included thus giving a positive steering action to the strip in these positions. The water rinse section includes primary and secondary cold spray sections. The final sprays in the secondary rinse feed at a controlled rate direct from the mains to ensure that clean water is put onto the strip at this point. Water is subsequently circulated via primary and secondary recirculating tanks to the preceding sprays, and thence to Acid Regeneration and Neutralising Plants as required.

The Fume Extraction System includes two fans and scrubbers. During normal operation with all tank covers in place, one fan will be in operation, but with both fans working it will be possible to open four tank covers (equal to half a tank length) at any point in the pickling section, the additional fan capacity being capable of extracting fumes from the uncovered sections. The main fume duct running along the tank is made a constant diameter to enable adequate extraction to be effected even when tanks are opened at points furthest away from the fan take-off

Auxiliary external extraction is provided where the strip enters the pre-heat tank and leaves the hot water dip tank.

The strip dryer, instead of being the usual hot air type, is an air-knife dryer in which high-velocity ambient-temperature air blasts water from the surface of the strip into a collecting trough. The heat remaining in the strip evaporates any remaining moisture.

The strip then travels via a two-roll steering unit and bridle to the exit storage loop which is of similar form to the entry loop but with only one car and a storage capacity of one minute, which is sufficient to allow change-over from one tension reel to the other.

Edge Trimming

The strip is pulled from the exit storage loop by a four-roll bridle and fed into a free-hanging loop which it leaves via a roll quadrant provided with side guides. A strip edge notcher is situated before the edge trimmers to enable the strip width to be locally cut back, thus enabling the trimmer blades to be set to the required trimmed width.

Two tandem edge trimmers and scrap cutters are provided, each trimmer being provided with sufficient head opening to allow blade changing to be carried out whilst the line is running. As it is felt that pull-through trimming will be possible on this line, No. 1 Trimmer is not in the initial stage provided with a drive, but provision is made to enable a drive to be fitted if required.

No. 2 Trimmer is a fully driven unit.

In addition to the usual centre and edge hold-down units mounted between the trimmer heads, a five-roll undriven leveller type unit is situated before each trimmer to stabilise the strip for trimming.

Scrap ribbons are chopped by scrap cutters of the double rotor type, each unit comprising two adjustable heads with a pair of four-bladed rotors. Scrap pieces are delivered by chutes onto a steel slat conveyor in the basement and thence to an inclined belt-and-slat conveyor which carries the scrap up to above ground level and into skips set down in two alternative positions.

Oiling and Recoiling

A four-roll bridle follows the trimming section, this unit providing both initial tension to pull the strip through the trimmers, and then back-drag for recoiling.

A single upcut shear parts the strip, and if required, removes the weld, scrap pieces falling into a skip mounted as a hydraulically operated trolley.

Oil is applied to both sides of the strip by a two-roll oiling machine in which oil is applied in pre-determined quantities by an Alemite 'Koter King' system to flannel rolls and from there to a pair of chrome-plated steel rolls which apply the oil to the strip. Two separate oil supply systems, for sheet and tin oil, supply oil to interchangeable oiling heads, thus avoiding contamination of the two types of oil.

Strip is recoiled on two tension reels, each provided with both drum gripper slots for gripping the leading end of the strip, and pendulum-type belt wrappers. The reels are mounted on slides and are provided with automatic edge control to ensure straight-sided coils.

Coil Unloading

Coil Carriages of similar form to those at the entry end, except that the cradles are provided with idle spin rolls, transfer coils from the reels to walking-beam conveyors.

2. Some Design Aspects

2.1 Coil Size/Outputs

The Ebbw Vale Pickle Line is designed to run at pickle speeds up to (305 metres/min) 1000 ft/min. However, for the first two years of operation it may have to handle an appreciable number of light coils of short lengths. These small coils exert a considerable influence on the line operating speed and production rate will be reduced. It is interesting to examine the effect of these small coils during initial operation of the line.

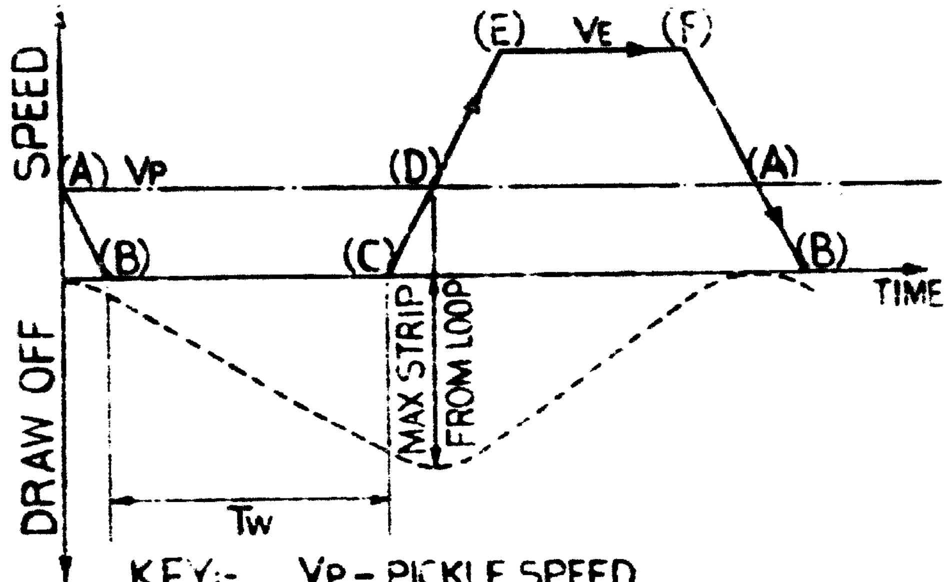
The entry section is stopped during welding and the entry loop is a buffer store of strip to enable the pickle section to continue running. After welding, the entry section is run at overspeed in order to refill the loop. The problem of running short coils at maximum line speed is that they run out before the entry loop is refilled, and so eventually the entry loop is depleted to such an extent that the whole line has to be stopped for welding, and this is undesirable as it leads to uneven pickling. It is therefore better to reduce pickling speed to the point at which constant speed can be maintained within the pickling section.

Fig. 4 shows the speed cycle for the entry section. The entry section is stopped for a period of 102 secs. then accelerates to an overspeed $V_e = V_p + 458$ in order to refill the entry loop, and then slows down to the pickle section speed V_p. The relationship between coil length and entry/pickle section speeds for maintaining constant speed in the pickle section is as follows.

$$L = \frac{V_p V_e}{V_e - V_p} \cdot \left\{ T_w + \frac{V_e}{\sigma} \right\}$$

Fig. 4

Entry section speed cycle



KEY:-
- V_P – PICKLE SPEED
- V_E – ENTRY SECTION SPEED
- T_W – ENTRY SECTION STOP TIME
- α – ACCELERATION RATE

(1) STRIP DRAWN FROM LOOP $S_{MAX} = V_P \left(T_W + \frac{V_P}{\alpha}\right)$

(2) MINIMUM COIL LENGTH L TO MAINTAIN CONSTANT PICKLING SPEED V_P

$$L = \frac{V_P V_E}{V_E - V_P}\left(T_W + \frac{V_E}{\alpha}\right)$$

Pickling speeds for coils of various lengths as given in Fig. 5.

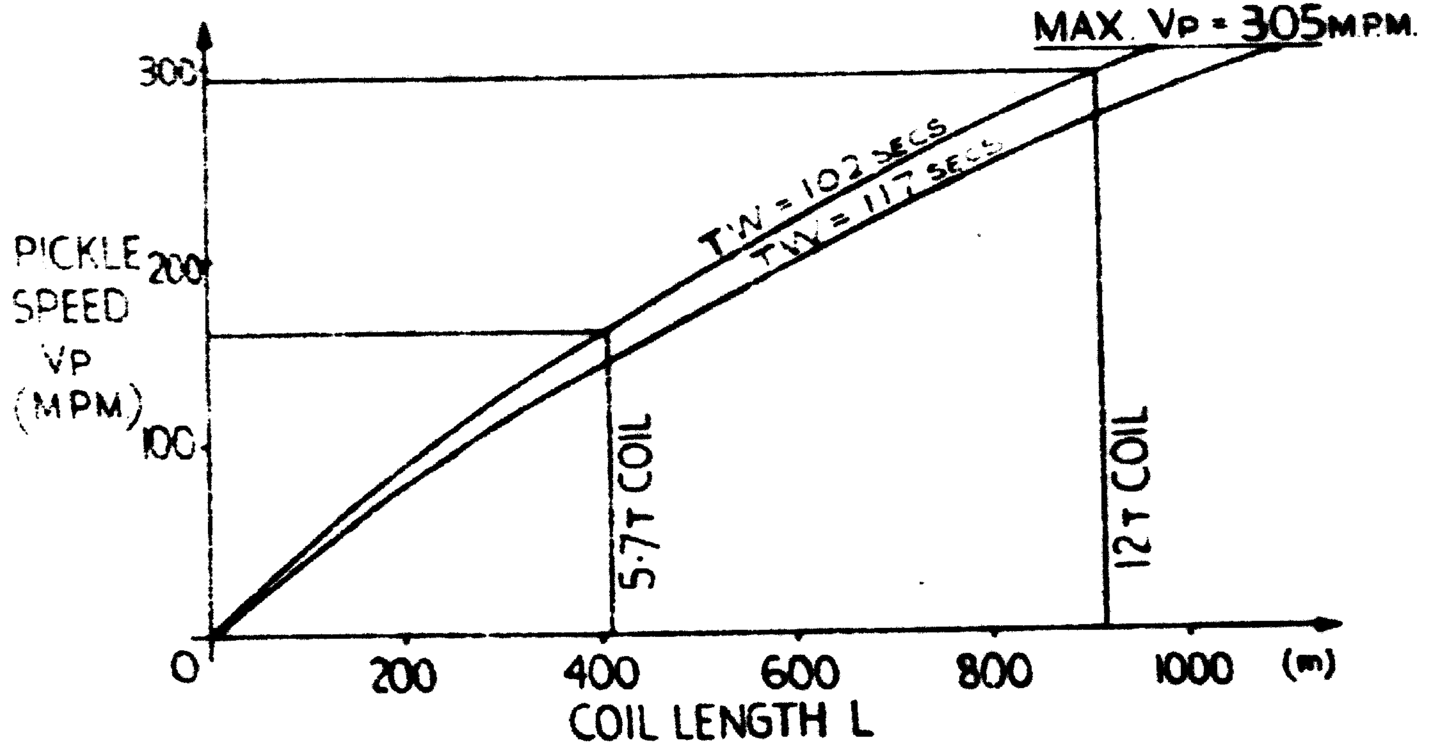
Initially the pickle line will have to use some incoming coils of 5.7t and 12t weight, which for average thickness 2 mm and width 864 mm gives strip lengths of 409 and 913 mpm respectively. Fig. 5 shows that a pickle speed of only 162 mpm can be maintained for the 5.7t coils and 293 mpm for the 12t coils. The line output is therefore drastically reduced for small coils. In fact, the line will only run at 305 mpm (1000 fpm) for coils whose lengths exceed 980 metres (approximately 12.8t).

Extra delays in the entry section can have considerable effect on output when handling short coils. Fig. 5 shows two curves, one for a total stop time of 102 seconds which is the design feature for the line and another curve for a stop time Tw = 117 secs corresponding to a delay of 15 secs per coil. The extra 15 secs delay in coil handling would reduce output from the line by about 10%.

The other significant factors effecting output are the acceleration rate and the maximum entry overspeed. Acceleration times could be reduced but would greatly increase the cost of electrical and mechanical drives quite disproportionately, e.g. halving the acceleration times would increase output by less than 5% but some of the main-drive powers could be doubled. An increase in overspeed would also have little effect on output and could not be justified against the extra cost and wear and tear of equipment at higher speeds.

The message is quite clear - high outputs from pickle lines require large coils.

Fig. 5 Fickling speeds for short coils



(The exit storage loop can be studied using the same expressions given above, but the stop time for coil changing should be taken to about 30 secs. It will be found that the exit end is not critical and will not reduce the pickling speeds if coils taken from the line are more than 10t, and it is likely that much bigger coils will be built-up).

2.2 Control of Strip Speed and Tension

Fig. 6 shows the design tensions for the line and Table 1 lists the main line drives and indicates the speed and tension setters for the various sections of the line.

Table 1

	Speed Setter	Tension Setters
Entry	No. 1 Bridle	Pay-Off Reel
Entry Loop		Winch
Process Section	No. 3 Bridle	No. 2 Bridle/Probe/ (Tensiometer)
Exit Loop		Winch
Exit	No. 5 Bridle	Tension Reel/Free Loop

Process Section

Section speed is controlled by the No. 3 Bridle.

Minimum tension within the Process Section occurs in the first tank : drag on the strip owing to friction at sills and squeegee rolls etc. causes an increase in tension as the strip passes through subsequent tanks so that maximum tension occurs in the last tank. The design tension at entry to the process section is sufficient to keep the heaviest strip clear of the bottom of the tanks.

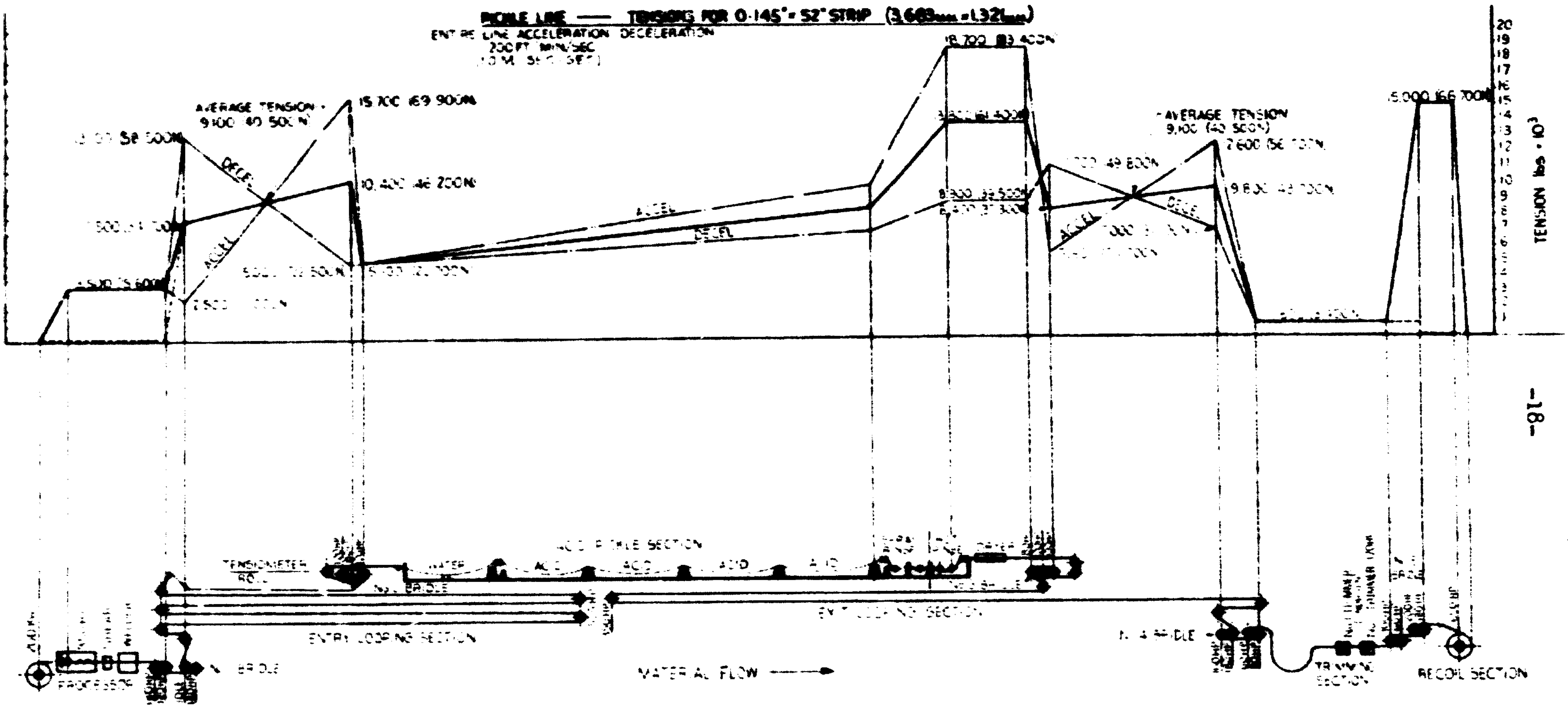


Fig. 6 Strip tensions and powers

The No. 2 Bridle sets the tension at the entry to the process section. A capacitance probe is mounted in the bottom of the No. 1 tank to detect strip position and the signal from the probe is used to control tension from the No. 2 bridle and so keep the strip within 100 - 500 mm distance from the probe. This ensures that strip is just clear of the skids in the bottom of tank No. 3, which has the lowest catenary point. Strip tension is higher in subsequent tanks, so that strip clearances are larger. It should be noted that the capacitance probe is in the pre-heat hot water tank where corrosive conditions are not so severe as in the acid tanks.

A tensiometer is also provided to indicate strip tension and this could be adapted to control tension from the No. 2 bridle in case of probe failure. However, the operators would then have to manually adjust the No. 2 bridle tension setting to suit the various changes in strip cross-sectional area since tension must be set in proportion to strip area.

Fig. 6 shows the drastic increase in tension within the process section, the set entry tension of 22200 N (5,000 lbs) at the No. 1 tank increasing to 62300 N (14,000 lbs) under constant speed conditions and 84500 N (19,000 lbs) during acceleration in the No. 5 tank. The rise from 62300 N (14,000 lbs) to 84500 N (19,000 lbs) represents the traction required to overcome the inertia of strip and rolls in the tanks during accelerating conditions. The 40000 N (9,000 lbs) rise from 22200 N (5,000 lbs) to 62300 N (14,000 lbs) is due to a number of factors, but chiefly Liquid Drag, Friction Drag and Bending Drag.

Liquid drag takes the form of viscous drag on the strip as it is pulled through the liquid in the tanks and through squeegee rolls at high speed. HW carried out tests (1) to measure viscous drag some years ago in connection with tension control in ETLs and this data is directly applicable to the pickle line. (It is interesting to note that the reaction on the liquid from strip drag in the tanks amounts to about 2220 N (500 lbs) and this horizontal force acting on the liquid causes a difference in surface level of about 16" from the entry end to the exit end).

Friction drag needs little explanation, being merely the effective weight of the strip times co-efficient of friction against the supporting sills. Co-efficient of friction was taken as 0.1, this being considered a safe value.

Strip is bent in passing over deflector rolls; if the strip is bent beyond the elastic limit, then work has to be done to pull the strip along. The effects of bending beyond the elastic limit are well-known and a method of calculating the work done is described in a previous paper (2). The combined effects of Liquid Drag, Friction, and Strip Bending and Inertias have to be carefully considered in order to assess motor powers.

Loops

The loop car speed is entirely determined by the difference in speed of the entry and the process sections.

Mean loop tension is set by the load in the winch ropes acting on the moving loop cars. The drive motor is of course fully compensated for the inertias of motor itself, the gearbox, winch and loop car, so that total pull from the two ropes remains constant.

Friction and bending drag in the loops is not appreciable. However, there is a large fluctuation in strip tensions under accelerating conditions. The No. 1 bridle changes from a drag to a pulling condition as the line goes from constant speed to the accelerating case.

Similar remarks apply to the exit loop, but in this case it is the No. 3 bridle which changes from a pulling to a dragging condition during acceleration. The minimum design tension in the loops is set so that good tracking will be maintained.

Exit Section

A re-wind tension up to 67000 N (15,000 lbs) is available at the tension reel to help wind tight straight-sided coils. The No. 5 bridle sets the speed in this section.

A free loop is provided in front of the trimmers to enable strip to be accurately aligned for entry into the trimmers by means of side guides on the loop exit quadrants. This low-tension section at the trimmers makes it necessary to use large highly powered 4-roll bridles at the No. 4 and No. 5 bridle positions. "Free" loops are in fact very expensive.

Acceleration conditions in the line give rise to severe load cases for drive motors. Line acceleration needs to be chosen with care as it can have a drastic effect on motor sizes and costs. Motor ratings are also largely dictated by the frequency of stopping and starting the line and again it is seen that small coils have a further effect in increasing the costs of electrics.

Bending drag is appreciable even for the Ebbw Vale Pickle Line which handles strip only up to .145" thickness. Bending drag is roughly proportional to t^2/D where t = strip thickness and D = roll diameter. Its influence on motor powers is such that careful attention needs to be given to the choice of bridle and deflector roll diameters in relation to strip thickness and particular attention is required to the conditions of bending imposed on the strip at loop support arm rolls and at other rolls of small diameter. In fact, many pickle lines handle strip to $\frac{1}{4}$" thick, and in such cases it is essential to make a careful analysis of bending and acceleration tensions. It would seem sensible to consider bridle and deflector roll diameters of at least 60" for $\frac{1}{4}$" lines as the extra cost of the larger rolls is probably outweighed by lower power losses and cheaper electrics.

2.3 Strip Steering

Fig. 1 shows the position of the main steering rolls in the Pickle Line. These rolls are positioned to keep the strip running centrally at critical points at the ends of the long horizontal runs at entry and exit from the loops and process sections. Two kinds of steer rolls have been employed. Nos. 1 and 4 steer rolls are the double roll type in which both rolls are mounted on a common frame which can pivot in a plane normal to the incoming and outgoing strip. In effect the exit roll is moved laterally in order to put the strip on to centre line. This type of steering roll is very accurate and stable in control. It has no tendency to distort the strip and spoil shape because the incoming and outgoing strip is subjected only to a quite insignificant twist. However, this steering system does have some limitation as it makes no correction to the position of the incoming strip. The use of this type of steering roll was dictated mainly by the plant layout. Strip will be paid off centrally from the pay-off reel and tension should keep the strip aligned centrally at No. 1 bridle. The distance to the No.1 steer roll is not too great and the amount of strip wander should be well within the correction range of the No. 1 steering roll. In the case of the No. 4 steer roll it should be noted that the strip is guided by steering squeegee rolls within the pickle tanks and past experience has shown that these rolls work well so that again very little correction should be needed at the No. 4 steer roll position.

Elsewhere at the ends of the loop cars runs, a new type of guide roll has been employed which is a steer roll mounted on a linkage as shown on Fig. 7. This type of roll is actually a development of an earlier type of self-aligning squeegee roll developed and patented by HW (3).

This type of steer roll does move laterally so that there is an immediate response to sideways movement of the strip, but the geometry of the linkage is such that in moving sideways the roll is also made to move out of alignment and becomes tilted in relation to the strip. The operation of this type of roll is :

a) A lateral translation of the roll to put the strip back towards centreline.

b) Simultaneous tilting of the roll which causes the strip to "creep" continuously over the roll towards centreline, thus enabling the roll itself to move towards some equilibrium point near centreline, the position of which will depend upon the particular shape of the strip being handled.

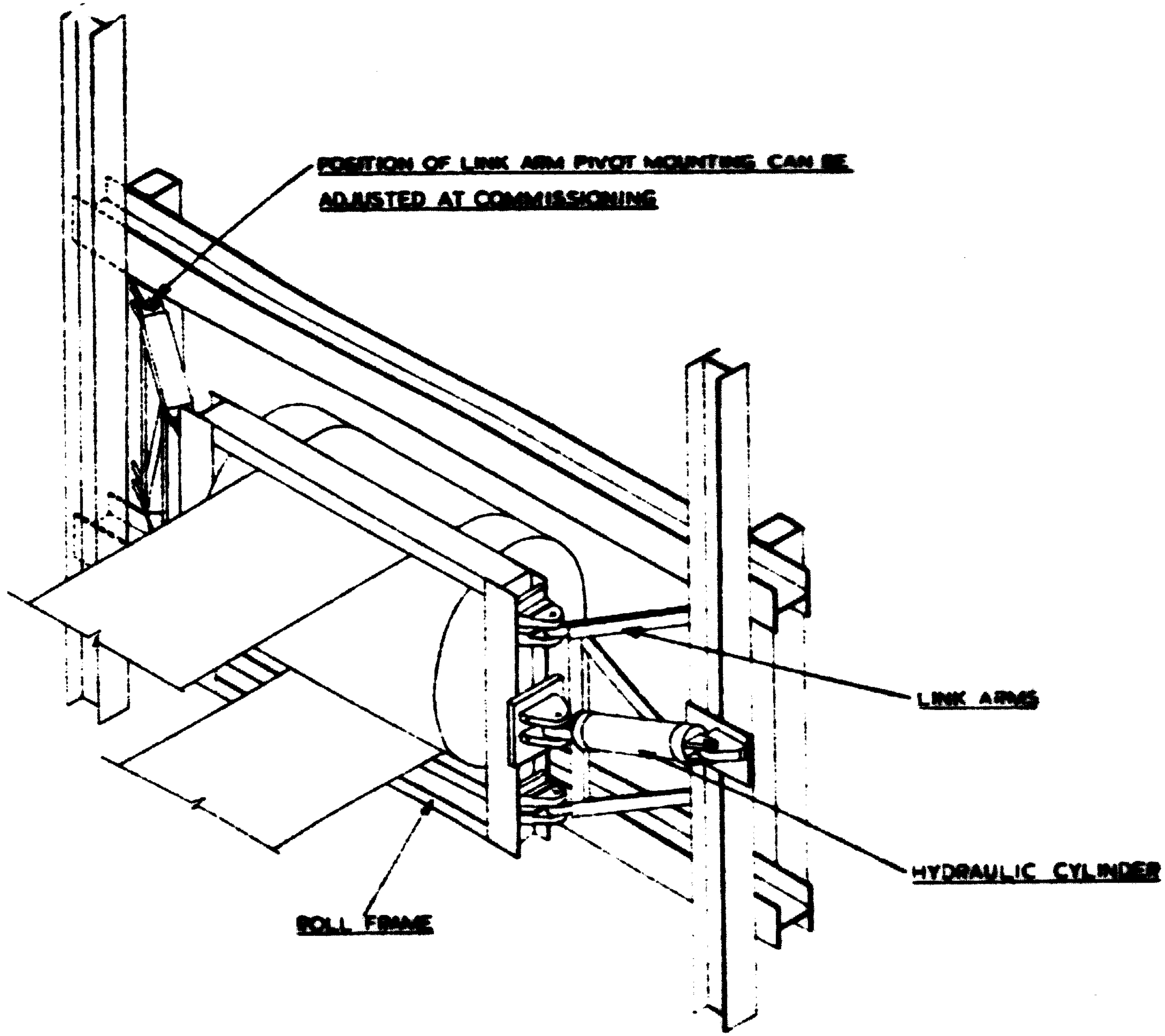


Fig. 7 Guide roll

This means that the strip is not only centred on the outgoing side but is also brought back onto centreline on the ingoing side and this is achieved with only the minimum amount of movement by the steer roll itself. The correction range of this type of roll is far greater than that of the double roll type previously described. Loop car travel is of the order of 500 ft (153 m) so that badly shaped strip if left to its natural course could wander a distance measured in feet rather than inches and under these circumstances the greater correcting capacity of the link roll seems essential.

The position of the fixing point for the links can be adjusted so that the instantaneous centre or pivot point can be made near to or far away from the roll; this enables the sensitivity of the roll to be changed and biased towards the "lateral translation" or "tilting mode" of correction. Final position of the links will be determined during commissioning.

Provision is made to obtain some steering effect with the loop support arms. These arms are mounted in pairs on opposite sides of the line at 12m pitch along the loop car runs. Adjustment of the length of a link in the actuating mechanism for the support arms enables them to be set at a slight angle to the line so that the arms make a herringbone pattern. This has a slight centring effect on the strip.

Steering squeegee rolls are provided within the Process Section. Such rolls have been used quite widely and they work well. The squeegee roll at exit from the Rinse Section is not power actuated; it is mounted on links and is self-aligning to the strip. Power actuators can be added later if found necessary. Conventional fixed squeegee rolls can cause bad tracking of strip and the self-aligning rolls are preferred.

2.4 Support Structure and Tanks

Much of the BSC bridge structure is exposed to the weather. The main beams are pinned to columns at one end and have a roller slide joint at the adjacent column which permits temperature expansion to take place. The main tank support columns of the HW structure are positioned over the bridge columns to isolate them from the expansion movement of the bridge and to transfer most of the dead load directly to the bridge columns. Intermediate columns are provided to help carry the loop car support beams but these columns do not share in carrying tank dead loads.

Pickle tanks are delivered to site in sections about 7 metres long and the tank is finally welded at site to form a continuous tank 170 metres long. Site welds are rubber covered after all welding has been completed. The tanks are about 3 metres deep and, because they are very stiff compared to the support beams of the structure, they inevitably carry most of the dead weight arising from bricks, liquid, tanks, and other equipment mounted on the tanks. The tanks are therefore designed to be entirely self-supporting, transferring their full weight to the main columns without help from the support beams beneath the tanks. The upper beams spanning the main columns are designed for the loads arising during erection when sections of the tanks will be carried on them before they are welded together and these upper beams are also designed to be able to support the full weight of the tanks and bricking etc. for the extreme emergency of a tank collapse, but under normal operation these support beams do not help to carry tank dead loads. A drip tray is mounted on the beams to collect spillage from tanks and the drip tray is big enough to take all the liquid from one of the pickle tanks.

Bolted joints were dismissed as impractical for the pickle tanks. It is difficult to design such joints to carry shear and bending loads because flanges would have to be rubber-covered, and in the past there has been leakage at such joints.

The tanks are carried on ptfe sliding bearings on top of the main columns. This allows thermal movement of the tanks to take place and minimises friction forces applied to the support structure. Thermal expansion forces from the tanks and support structure, together with the forces arising from strip tensions, exert horizontal shearing forces of about 200 t maximum through the end bracings and these forces have to be carried by the bridge columns to the foundations.

The Krupp Pickle Line built by Demag makes an interesting comparison with the Ebbw Vale Line (Fig. 11). The notable feature of this line is that the pickle tanks act as simple beams spanning between columns. Tanks are 20 metres long and have to carry their own weight. A bellows-type joint is used to interconnect the tanks which permits end rotation and takes up longitudinal expansion. The loop cars and other mechanical equipment are mounted on a separate support structure. This design had to be adopted in order to take care of ground subsidence and provision is made to jack up the main tank support columns when necessary. The rigid type of support structure and tank system adopted for Ebbw Vale was not practicable at Krupp.

2.5 Process Section

HCl pickling has superseded H_2SO_4 within the last ten years. The relative merits of sulphuric and hydrochloric acid pickling have been discussed very fully in previous papers (4, 5, 6) but broadly there are three reasons why HCl pickling is now attractive.

a) HCl can be regenerated from ferrous chloride in the spent pickle liquor to give a closed process which can be roughly represented by

$$FeO + 2HCl \underset{\text{Regeneration}}{\overset{\text{Pickle}}{\rightleftharpoons}} FeCl_2 + H_2O$$

(Not quite correct; the regeneration process produces Fe_2O_3 - see later)

Thus the process does not produce a significant effluent problem - now a most important consideration.

b) HCl pickling produces better strip quality. Ferrous chloride is soluble and can easily be rinsed away, whereas the sulphate salt arising from sulphuric acid pickling is relatively insoluble and any residues on the strip can later form pickle stains. The high solubility of ferrous chloride also means there is no sludge formed in the pickle tanks, which in the case of sulphuric acid makes frequent cleaning of the tanks necessary together with neutralising of the sludge. HCl attacks the three oxides of iron and can remove them completely, but sulphuric acid attacks the base steel and does not necessarily remove rolled-in scale which can cause surface marking after cold rolling.

c) HCl pickling is faster than sulphuric acid pickling, so that the output from a given size of pickling installation is higher.

There is one disadvantage with hydrochloric acid in that the acid fumes readily. This means that tanks must be very carefully sealed and adequate means for fume extraction have to be provided, together with careful choice of solution concentrations and temperatures. The amount of acid vapour formed increases with the concentration of acid and ferrous chloride present in the solution (6), and with operating temperatures. Also vapour loss in fume extraction carries away heat and represents 40% of the heating requirement for the line.

In the Acid Regeneration Plant, acid is regenerated from the SPL by a process of spray roasting. The roasting process is done at high temperature. SPL is sprayed into the upper part of an oven directly heated by burners. The water and HCl are evaporated and particles of $FeCl_2$ formed react with these gases as they drop through the oven according to the equation

$$2FeCl_2 + 2H_2O + \tfrac{1}{2}O_2 = Fe_2O_3 + 4HCl$$

The end products are separated; ferric oxide is taken out in the form of a powder and HCl is returned to the pickle tanks, together with a small amount of make-up acid (up to 10% has been reported from other lines) to replace small losses in the regenerating plant and in carryover from the acid to the rinsing sections of the pickle line.

Apart from small losses, the pickling and regenerating processes form a closed system, so that any water added to the system must be removed at some stage to prevent progressive dilution of the acid. Furthermore, heating requirements and the cost of the acid regeneration plant depend mainly on the volume of the liquor to be handled; it follows that the amount of water in the SPL should be kept to a minimum and acid and ferrous chloride concentration should be as high as is practicable. No extra water should be introduced into the system from such things as steam injectors.

It can be seen then that choice of acid strengths and temperatures must be a matter of compromise. For rapid pickling, acid concentrations and temperatures should be as high as is practicable, whilst the amount of ferrous chloride in the solution has to be limited as this tends to inhibit pickling. For efficient regeneration on the other hand, ferrous chloride content should be as high as possible. There is also an upper limit to temperatures and acid and ferrous chloride concentrations set by the fuming rate which determines the size of the fume extraction system and involves a significant heat loss from the system.

The problem of dilution is dealt with as at Nippon Kokan (5), who appear to have been the first to use an entry hot-water tank for pre-heating the strip. Direct steam heating is the most effective form of heating and the condensate arising in the hot-water tank merely overflows and is taken from there to water recovery plant. Squeegees are provided to prevent carryover from the pre-heat tank into the acid section. Acid tanks are heated by pumping the acid to heat exchangers at the side of the line and the only water introduced into the acid section is that carried over from the entry hot water tank which is limited by the squeegee rolls.

Fig. 3 shows the process section conditions for the pickle line, together with a graph reproduced from Ruthner (4) showing how acid concentrations and temperatures affect pickling rates. The residence time in the acid tank is about 20 seconds at top line speed, which corresponds to the required pickling time as given by the graph for acid strengths 4.8% to 16.1% at temperatures 93^{o}C to 78^{o}C. Also note the long pickling time required at low temperatures. At 50^{o}C, which may be the effective mean temperature of the strip in the pre-heat tank, the pickling rate would only be about 1/5th of that in subsequent tanks and this shows clearly that substitution of a hot-water tank for an acid tank has negligible effect on pickling capacity.

(The pickling rate for sulphuric acid is also given and shows the increased rate of pickling for hydrochloric acid).

The changes in hydrochloric acid and ferrous chloride levels through the tanks correspond to the chemical changes involved in pickling in each tank and correspond overall to a pickling reaction with 0.45% of the weight of the incoming strip as iron in iron oxide, i.e. 0.45% iron loss. The acid regeneration plant is rated to deal with 734 kgm per hour of iron as chloride and this represents 0.45% iron loss from 27,000 tons of strip per week.

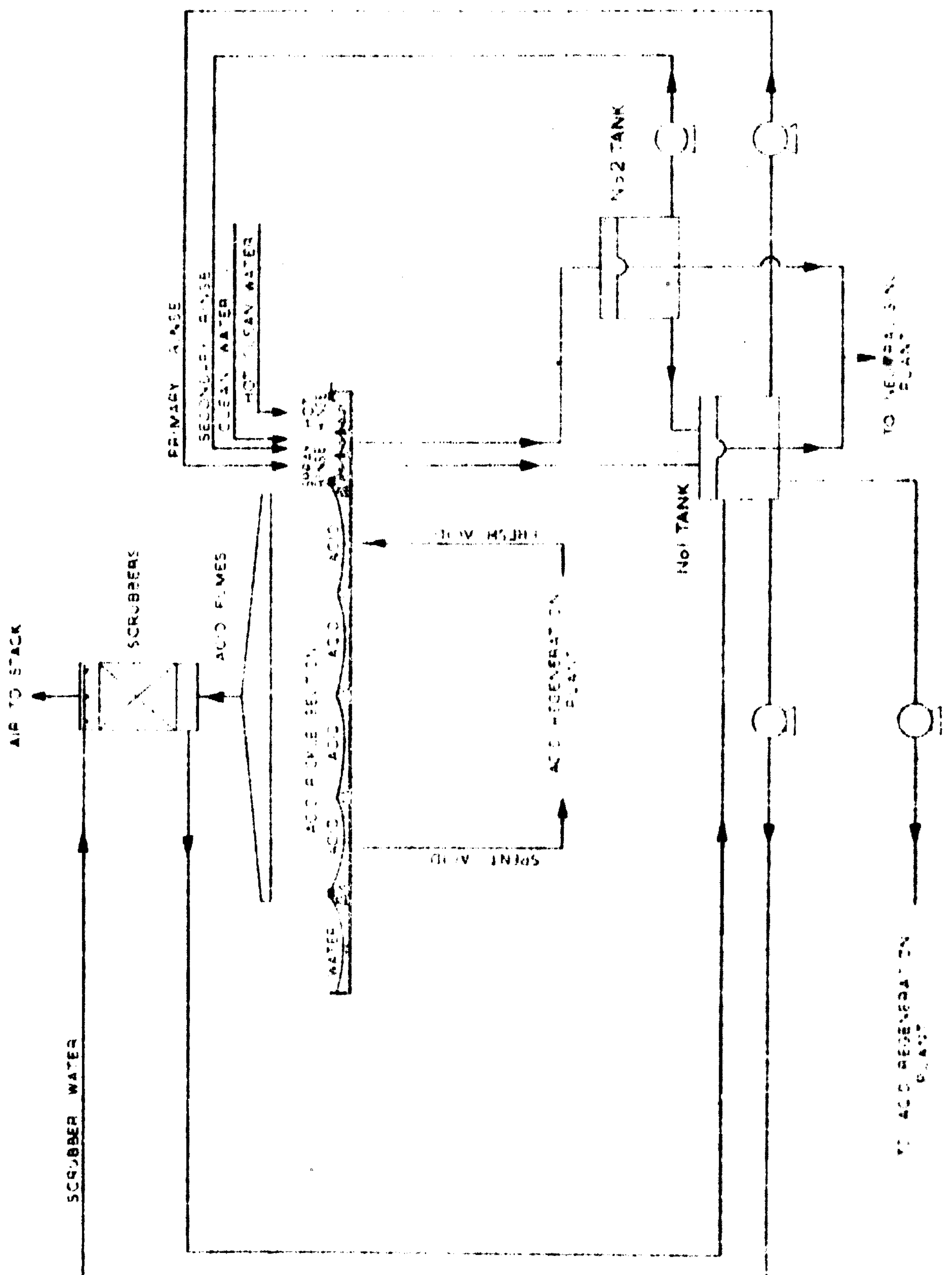


Fig. 8 Flow diagram

Strip has to be thoroughly rinsed when it leaves the acid section because acid and ferrous chloride on the strip would cause surface stains.

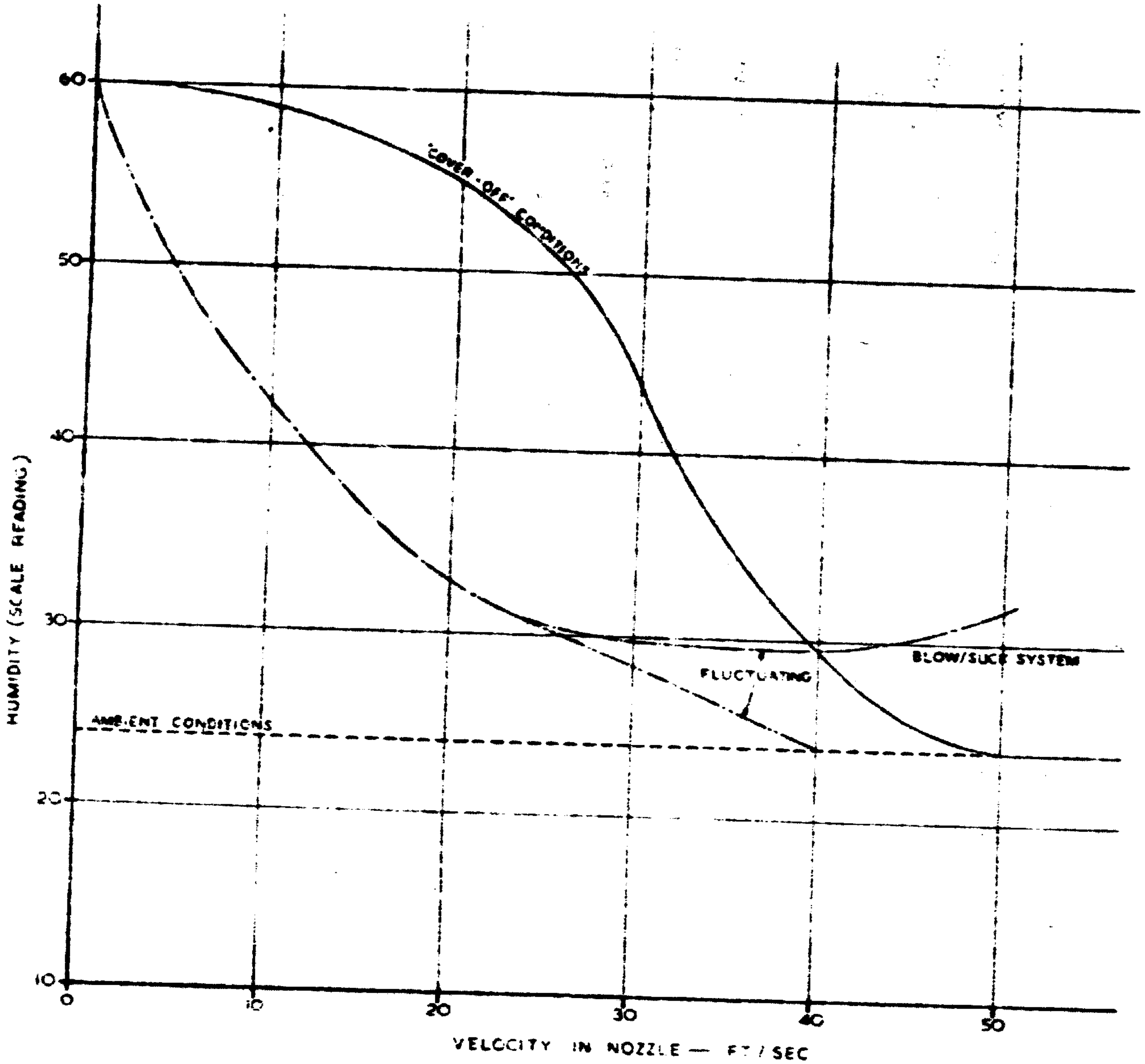
Fig. 8 is a simplified diagram of the rinsing arrangements and overall flows for the line. Rinsing is done in two stages. Water is recirculated at rates up to 67,500 kg/hr in the Primary and Secondary rinse sections from holding tanks Nos. 1 and 2. The acid level of the secondary rinse water is controlled by continual addition of clean water in the exit hot-water tank and the secondary rinse, and acid level of the Primary Rinse is controlled by adjusting the amount of relatively clean water going to tank no. 1 from tank no. 2.

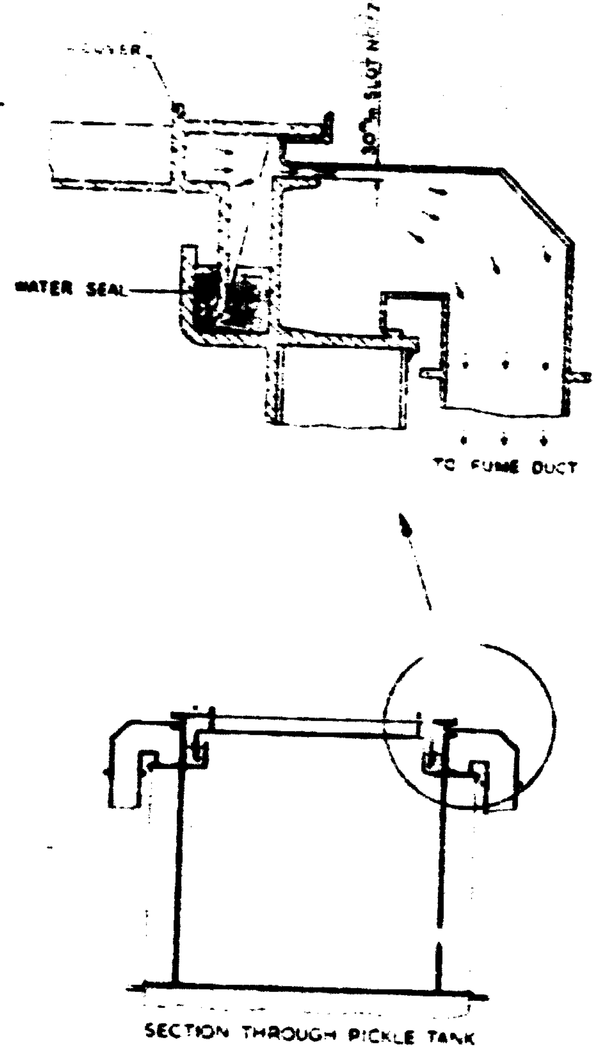
Provision is made for the strip to be sprayed with rinse water immediately before the squeegee rolls at exit from acid tank no. 5. This washes away some of the acid on the strip and reduces the amount of acid carried through the squeegee rolls because of dilution. (The small amount of water added to the no. 5 acid tank is needed as make-up water and is taken into account in adjusting the concentration of fresh make-up acid). Data given by Miltenberger (ref. 6) indicates that up to 370 kg/hr of liquid could pass through the squeegee rolls at a strip speed of 1000 ft/min, and the acid/chloride contained in this liquid has to be removed in the rinse section. Water recirculating in the Primary Rinse Section will be held to an acid concentration less than 1%, so that liquid carried by the strip through to the secondary rinse will be diluted to this extent. Water recirculating in the secondary rinse is controlled to a maximum level of about 200 ppm acid content (with provision for control to much lower values by increasing the flow of clean water). Furthermore, clean water is introduced to the secondary circuit by spraying it directly onto the strip so that strip is washed with clean water as it leaves the rinse tank. This is followed by a clean hot-water dunk and finally another clean water spray. Contamination level when strip finally emerges from the rinse section should be quite negligible. Rinsing is followed immediately by drying.

Note that the water from the Primary Rinse Circuit is also used to clean the fume exhaust gases so that it captures most of the acid lost from the line in fume and liquid carried out by the strip. Most of the liquid from the No.1 tank is then passed to the regeneration plant where the acid is recycled back to the Pickle Line.

Acid Losses from the line consist of Stack Losses and Losses in Rinse Water passing to the neutralising plant. The amount of acid loss will depend upon such things as Scrubber Efficiency and Amount of Fume, Amount of Rinse Water used and Effectiveness of Squeegee Rolls with Line Speed. Calculations show that acid losses from the line could be as low as 30 kg/hr, which is of the order of 3% of the acid involved in the Pickling Reaction. Some losses take place in the Acid Regeneration Plant. Overall, an acid loss between 5 - 10% is to be expected, and this amount of fresh acid has to be introduced into the line in addition to regenerated acid.

HCl vaporises fairly readily so that care has to be taken to prevent acid fumes from escaping into the surroundings. Tests were done during the initial stages of design to determine the most effective way to eliminate fume.





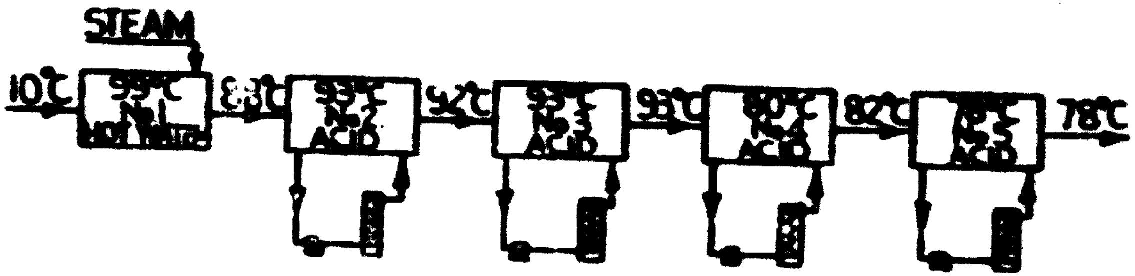
EFFECT OF NOZZLE VELOCITY ON LEVEL OF FUME EMISSION

FIG. 9

During normal operation, with all tank covers in place, fume is pulled from the line by means of one fan and extraction from each end of the Pickle Section. Pressure inside the pickle section tanks is reduced so that air is drawn into the tanks through any gaps between tank covers etc. and there is no outward movement and escape of acid fume. Fig. 9 shows a water seal at the sides of the covers which prevents fume escaping there. Each cover is provided with a flexible rubber flap at each end, which makes a lap joint between the covers to prevent fume escaping and also permits covers to be lifted and replaced in any sequence.

The fume extraction system also deals with a cover-off condition, when a length of tank up to 42'-0" can be exposed. Both fans are then brought into operation and air is extracted, local to the open tanks, through the nozzles shown in Fig. 9. Tests were done during the initial stages of design to determine the best form of nozzle and the flowrates needed to prevent escape of fume. Fig. 9 shows how flowrate has to reach a certain minimum value before fume is contained. (Another curve is shown for an alternative design which involved blowing a curtain of air across the tank from one nozzle and extracting the air through the nozzle at the other side of the tank. This arrangement showed no advantages and was not as effective as the scheme adopted).

Heat losses from the line are significant. These are summarised in Fig. 10. Total heat requirement at 1000 ft/min line speed is 4,500 kw,



TANK	TEMPERATURE	STRIP HEATING	FUME LOSS	OTHER LOSSES	TOTAL HEAT LOAD
1	99°C	[illegible]68 × 10³	0·10 × 10³	0·15 × 10³	2·93 × 10³
2	93°C	[illegible]·16	0·50	0·01	0·67
3	93°C	[illegible]·02	0·50	0·06	0·58
4	80°C	[illegible]·41	0·41	–	–
5	78°C	[illegible]·12	0·41	0·03	0·32
	TOTALS	2·33 × 10³	1·92 × 10³		4·5 × 10³
		KW	KW	KW	KW

Fig. 10 Heat loads

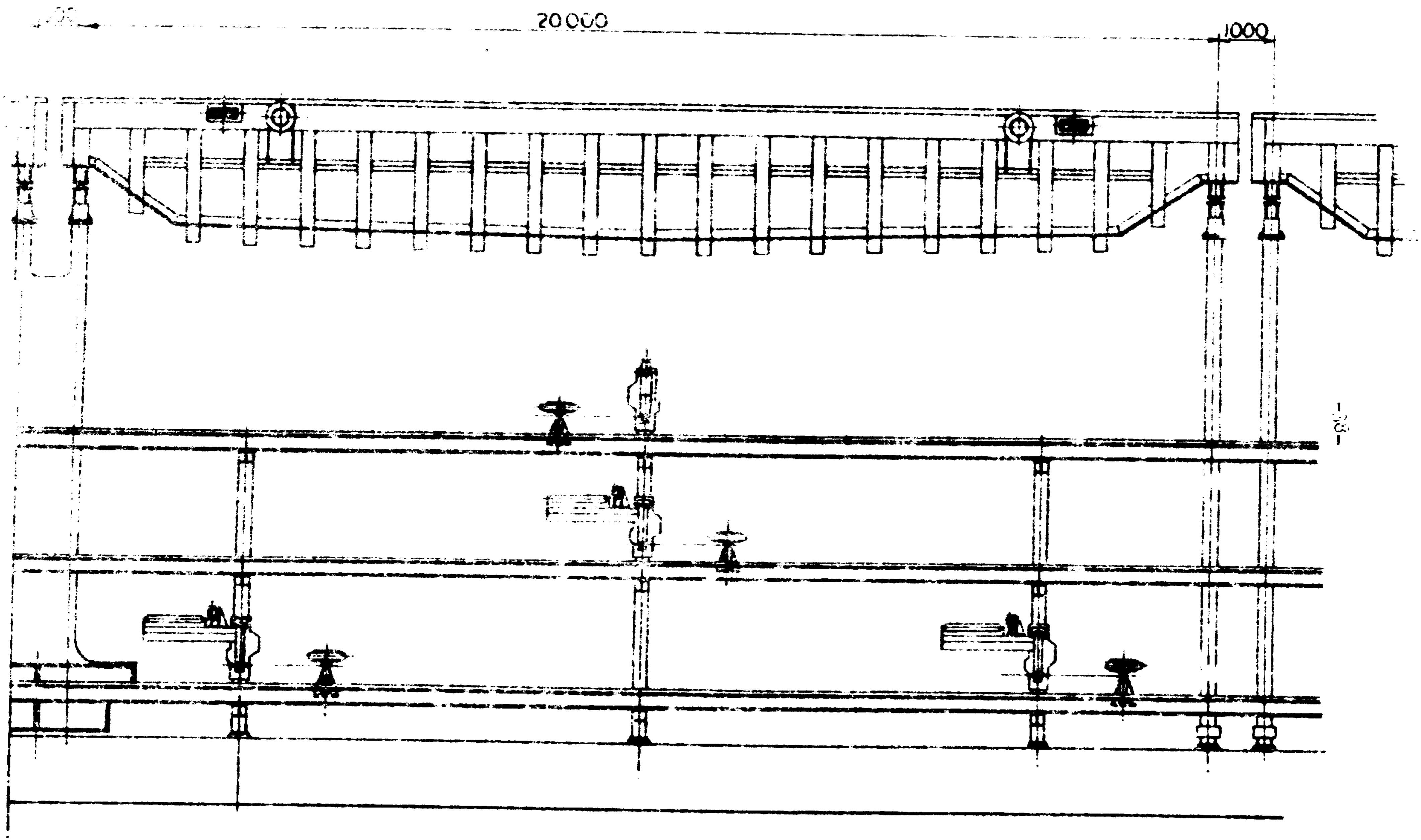


Fig. 11 Krupp pickle tanks

heat lost in fume extracted accounting for about 40% of this and heat required for strip heating accounting for the remainder. Other losses owing to convection and radiation from the pickle tanks, heat carried away by carry-over liquid, heat gained by pickling reaction etc. are insignificant.

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