Eighth Australasian Fluid Mechanics
Conference, University of Newcastle,
N.S.W., 28 November/2 December 1983.

# AN AIR SEPARATOR

E.P. GIDDENS

DEPARTMENT OF CIVIL ENGINEERING

UNIVERSITY OF CANTERBURY, CHRISTCHURCH, NEW ZEALAND

SUMMARY For a proposed, run-of-the river, micro-hydro scheme it was decided to utilise a greater flow than the reliable minimum stream flow. As there was no flow regulation at the turbine it was expected that air would be drawn in at the intake at times of low stream flow. To separate and vent such entrained air, an air separator was evolved experimentally in the laboratory and subsequently installed on the site. The form of the separator and its performance are described.

## A MICRO-HYDRO INSTALLATION OPERATING AT REDUCED FLOW

A typical micro-hydro scheme will have, by definition, a full-load output of up to about 25 kW and will provide an isolated electricity supply of single-phase, alternating current at 240 v and 50 or 60 hz for a farm or a native village. The primary cost emphasis in designing such a scheme is the minimising of the initial capital cost and, to this end, the installation is likely to take the following form:

Medium head, to avoid excessive penstock costs.
Medium discharge, to avoid excessive turbine costs.
Run-of-the-river, to avoid storage costs.
Fixed turbine geometry, very likely a reversed rotodynamic pump, to minimise machine costs.
Direct coupling between machines, for transmission simplicity.
Conventional 2-pole or 4-pole synchronous generator, with automatic voltage regulation.
Frequency control with a frequency-sensing, load-switching, electrical governor, automatically diverting the unused electrical demand to dummy resistive load banks and maintaining steady full load on the generator.
Overspeed protection on load rejection with a solenoid controlled brake.
Proximity to the user, to minimise electrical transmission costs.
Arrangements for automatic operation and minimum maintenance.

Such an installation, operating at full load and with no storage, would require to be taking less than the full flow of the stream. Surplus water would need to be flowing over the intake spillway to maintain the penstock running full. In sizing the installation, the decision has to be made as to the continuous discharge to be drawn from the stream. Hydrological data on low flows is unlikely to be available and, often, the safe minimum flow of a conveniently located stream will be less than necessary for the required power output. For these reasons, a design discharge greater than the safe minimum flow is likely to be adopted.

At times of low stream flow, when less than the full load discharge is available, air would enter the penstock at the intake and the turbine would be exposed to operation at reduced head and discharge with air entrained in the water. Shut down of the plant under these conditions would be normal. A small standby, petrol or diesel generator may be available, but it would still be preferable in most cases to continue running the hydro-plant at reduced power, if it were possible. To do this, the air would need to be extracted from the flow. The system would then, operating at reduced head and discharge, produce reduced power at the same voltage and frequency and would in fact, operate satisfactorily down to about 30% of full load before stability problems with the load sharing governor might be encountered. At very low system power levels, the incremental steps of the load banks of the load-switching governor may be too coarse for stable operation.

If the output power of a fixed geometry turbine operating at constant speed were to be reduced to 30% of full load, the head and discharge would each need to be reduced to about 60% of their full load values. The consequences of taking advantage of operation at reduced discharge would be either to reduce the shut down times at low flows or, by using a larger installation, to allow better use to be made of the normal flows. The typical variations of power, efficiency and head versus discharge, for a fixed geometry turbine operating at constant speed, are shown in fig. 1.

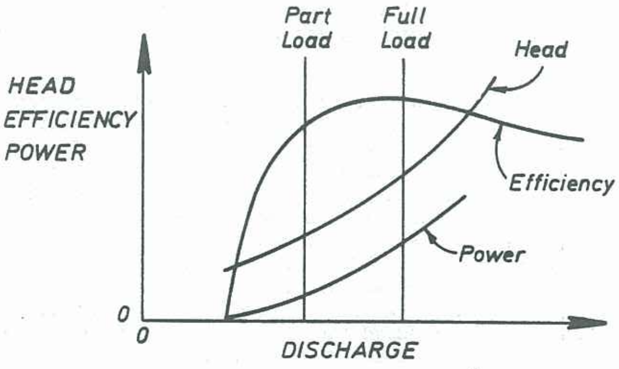

Figure 1

The water velocities in hydro-power penstocks are likely to be relatively low in order to minimise the head-losses and the dangers of water hammer. Water velocities around 1 m/s would be typical and air separation and removal at these velocities is a practical proposition.

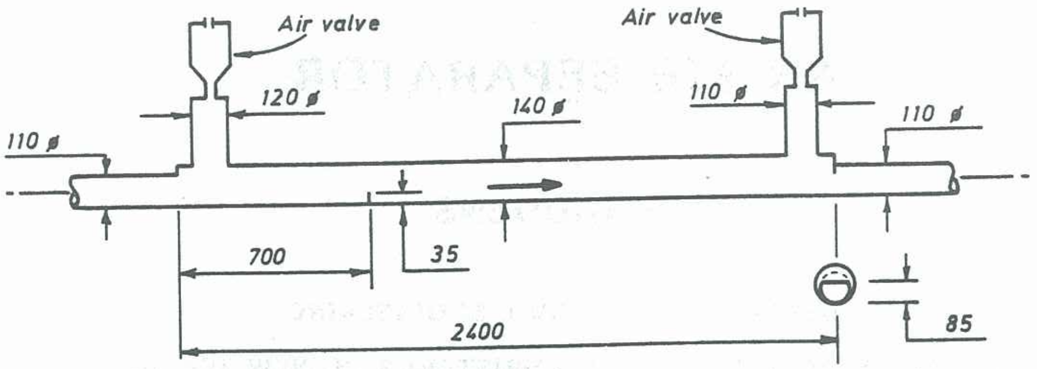

Figure 2

An experimental study in the Fluid Mechanics Laboratory of the Civil Engineering Department, University of Canterbury, Christchurch, New Zealand, by a group of final year students, lead to the development of a suitable separator for a proposed scheme for a high-country sheep station. Based on this study a separator was built and installed on the site. This paper is primarily concerned with the development and performance of the laboratory model.

## SITE CONDITIONS

The source of the water was a small mountain stream in a steep rocky gully. A full load, penstock flow of 12 l/s was proposed. The penstock was to comprise 600 m of 100 mm dia. asbestos-cement pipe with rubber-ring, push-on couplings. The terrain was such that full use, in the horizontal and the vertical directions, would need to be made of the deflection angles of the couplings. The gross head was 92 m and the net head 72 m. If the pipe were to be straight and uniformly sloping, uniformly supercritical flow could have been predicted and the air entrainment of the hydraulic jump calculated. However, the model study was started before the pipe route was finalised and it was assumed that, due to the unfavourable pipe configuration, air could become trapped and move down the penstock in long pressurised pockets. The separator was modelled to cope with both situations, of which the case of the trapped air was judged to be the more severe.

## EXPERIMENTAL DEVELOPMENT OF THE SEPARATOR

The separator was modelled, full size, in perspex and developed experimentally. The complete installation could not be modelled and only the section of the penstock pipes approaching and leaving the separator were provided.

The first test was conducted on an arrangement that had previously been found successful for removing relatively small quantities of air. In this form, the separator comprised an enlarged pipe section mounted eccentrically and fitted with an air chamber on the top at the downstream end. An automatic air valve was fitted in the top of the air chamber to vent to atmosphere the collected air. The enlargement reduced the water velocity and encouraged gravitational separation of the air. A baffle plate at the outlet contraction, further reduced the chance of air being carried into the outlet pipe. This arrangement was adequate for the relatively small quantities of air that resulted from the flow situation where supercritical flow in the penstock, at atmospheric pressure, terminated in a hydraulic jump upstream of the separator. This arrangement comprised the outlet section of the final separator design.

To simulate the circumstances when large pockets of trapped air arrived at the separator, water was supplied to the penstock under pressure and compressed air was injected in the penstock sufficiently far upstream for established flow regimes to arrive at the separator. The flow rates of water and air could be varied independently.

With the steep approach, characteristic of the site, it was found that supercritical flow under pressure could arrive at the separator and it became necessary to stabilise a hydraulic jump towards the upstream end of the enlarged pipe section. A low wall satisfactorily stabilised the jump but the air flow had to pass through the jump to get to the downstream air vent. With increasing air flow, the capacity of the downstream air vent was ultimately exceeded and the excess air passed right through the separator.

To cope with increasing air flows, a second collecting chamber was installed on the top of the upstream end of the enlarged pipe section, upstream of the hydraulic jump wall. This markedly improved the effectiveness of the whole arrangement and completed the final design.

In this form, the upstream vent coped with the violence of the approaching supercritical flow and the column of water and air in the collecting chamber effectively localised the hydraulic jump immediately below it. The downstream vent coped well with the small residual air passing the first vent. If the air flow rate exceeded the capacity of the upstream vent to exhaust air, the collecting chamber below it emptied of water and the control of the position of the hydraulic jump passed to the wall. The excess air was handled by the downstream vent.

In the course of developing the separator, the barrel was tried with upward and downward slopes but these proved unsuitable for one condition or another and the horizontal attitute was adopted. Initially, too, the collecting chambers were made of a much smaller diameter than the pipe they were collecting from. This was found to be unsatisfactory and the experience of increasing the diameter of the collecting chambers suggests that they should be of the same diameter as the pipe they are collecting from. This view is confirmed by Falvey (1980) who also recommends that the collecting pipe should have a vertical length of at least 1 diameter.

The final geometry of the model separator is shown in figure 2. In this form, the separator was finally tested for various flow rates of both water and air and different regimes of the approaching flow.

## AIR VALVES

The air valves used were standard waterworks air valves with 75 mm dia. floats. To vary the duty, the orifice sizes and float weights can be altered. For the laboratory tests the floats were made of solid ultra high molecular weight polyethylene (UHMWPE), which has a specific gravity of 0.94, and the orifices were enlarged to 3 mm diameter. In this form the valves would operate at gauge pressures up to 2½ atmospheres before the line pressure would hold the balls on to the venting holes.

## LABORATORY MEASUREMENTS

The water supply to the test installation was obtained from the laboratory low head system and the flow rate was measured with a Dall flow tube. The flow rates of the air vented from the two air valves were measured, in litres per second of air at atmospheric pressure, by timing the filling of light plastic bags of 60 litre capacity.

The penstock pipe immediately before the separator was arranged for adjustable slope with provision for air to be admitted at atmospheric pressure, when simulating a simple supercritical flow/hydraulic jump approach regime. Arrangements were made for the admission of air under pressure when simulating the case of trapped air being carried to the separator.

In the trapped air case, the separator was operated under a line pressure of about 1 atmosphere and the air was admitted to the penstock using a compressed air supply, pressure regulator and orifice.

## PERFORMANCE OF THE LABORATORY VERSION

The separator, developed for the trapped air case, handled the relatively small quantities of air arriving from the supercritical flow/hydraulic jump regime with ease.

For the trapped air case, the separator was tested at flow rates equivalent to the penstock running full at velocities of 0.75, 1.0, 1.25 and 1.5 m/s. For each water velocity, with the separator operating at a gauge pressure of 1 atmosphere, air was injected at flow rates of 1, 2 and 3 l/s of free air. The approach from the downward sloping pipe gave flow regimes which included:

(a) bubbles of air in the upper part of a full pipe, becoming more and more dispersed with increasing air content until

(b) fully dispersed flow occupied the full pipe.

(c) Under certain conditions fully stratified flow, with air over supercritical flow, occurred.

Slugging flow was not obtained with these approach conditions and a further test was conducted with a rising approach pipe which produced a type of slugging flow at very low water velocities.

For all cases described and tested, the separator was effective. The operation of such a separator is to reduce the entrained air and in all cases it is estimated that the separation was better than 95% and in many cases almost 100%. For this application, a few finely dispersed air bubbles are of no consequence. With the increasing penstock pressure they will probably dissolve before reaching the turbine.

For velocities in excess of 1.5 m/s the quantity of air not removed by the separator began to increase and a velocity of 1.5 m/s was considered to be an upper limiting workable velocity. At pipe velocities of less than 1.5 m/s, the majority of the air was vented from the upstream vent but at 1.5 m/s and an air flow rate of 3.2 l/s of free air the majority was transferred to the downstream vent.

A measurement of the head loss attributable to the separator when running full with no air flow showed a head loss of 140 mm of water for a flow rate of 12 l/s in comparison with a normal loss of 70 mm for the same length of pipe.

The test results are set out in the following table. In each square are given the following quantities:

The flow type - dispersed or stratified.
Upstream and downstream air venting flow rates - l/s of free air.
Separator gauge pressure, kPa.

| Water Flow; Pipe Velocity | Total Free Air Flow Rate | | |
|---|---|---|---|
| | ~1.0 ℓ/s | ~2.0 ℓ/s | ~3.0 ℓ/s |
| 7.1 ℓ/s<br>0.75 m/s | Dispersed<br>1.0; 0.0 ℓ/s<br>103 kPa | Dispersed<br>2.0; 0.0 ℓ/s<br>98 kPa | Stratified<br>1.5; 1.5 ℓ/s<br>98 kPa |
| 9.6 ℓ/s<br>1.00 m/s | Stratified<br>0.8; 0.0 ℓ/s<br>104 kPa | Dispersed<br>1.9; 0.3 ℓ/s<br>98 kPa | Dispersed<br>1.9; 1.2 ℓ/s<br>97 kPa |
| 11.9 ℓ/s<br>1.25 m/s | Stratified<br>0.7; 0.1 ℓ/s<br>104 kPa | Stratified<br>1.2; 0.9 ℓ/s<br>98 kPa | Dispersed<br>1.9; 1.3 ℓ/s<br>97 kPa |
| 14.2 ℓ/s<br>1.5 m/s | Dispersed<br>0.5; 0.2 ℓ/s<br>103 kPa | Dispersed<br>1.6; 0.5 ℓ/s<br>98 kPa | Dispersed<br>1.3; 1.9 ℓ/s<br>96 kPa |

Table 1

## PROTOTYPE SEPARATOR

The prototype separator was built in steel to essentially the same dimensions as the model and installed on the site at a vertical height of 28 m above the turbine. Both air valves were equipped with floats of UHMWPE. The upstream air vent was made 2.5 mm dia. and the downstream vent 1.6 mm diameter to cope with the smaller air quantities and with the full line pressure.

The installation has operated for considerable periods at reduced heads with no reports of problems due to air entrainment at the turbine. It is planned to take measurements of the performance of the prototype and report them to the conference.

## CONCLUSIONS

This study was for the purpose of addressing a particular case but it is hoped that the experience may be of assistance in considering other cases.

The principle conclusion is that the flow situation is well suited to an experimental solution.

By controlling the air supply the volumetric flow rate of the air fraction can be adjusted to accommodate a reduced pressure, independently of the water flow rate, and modelling can be done at the low pressures appropriate for the use of perspex pipe. Care has to be taken in visually assessing the air flow because of the lense effect of the curved pipe walls.

Very little literature appears to exist on the use and operation of air valves. If their use is restricted to venting high points in systems at rest, the operation will be quite straightforward. However, considering the difficulty, experienced in this study, of collecting air in flowing systems, it would suggest that more attention should be given to the methods of separating and collecting air as an aid to venting.

## ACKNOWLEDGEMENTS

The assistance of the New Zealand University Grants Committee in supporting research into micro-hydro power at the University of Canterbury is acknowledged.

## REFERENCES

FALVEY, H.T. (1980), Air-water Flow in Hydraulic Structures, U.S. Dept. of the Interior, Engineering Monograph No. 41.