The Institution of Mechanical Engineers.

(Midland Branch.)

HYDRAULIC RAMS.*

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[*Selected for Publication.*]

The hydraulic ram is a simple, ingenious, and useful machine for raising water where favourable conditions can be found for its installation. It is described in many text-books of engineering, but the information given is generally meagre. In this Paper brief particulars are given concerning a long series of tests and experiments, made mainly by the Author, extending over a period of several years. For the earlier experiments rams were used of the original type made by Messrs. Easton and Amos; but, as a result of the experience gained, a new design was adopted with which the later experiments were carried out, and with the results of which the Paper mainly deals. It has been called the "Anderson" ram, Fig. 1 (page 338), to distinguish it from the older pattern.

The principle of the hydraulic ram was explained by the Author's father (the late Sir William Anderson, K.C.B., D.C.L., F.R.S., a Past-President of this Institution) in his "Chatham" lectures on Hydraulic Machinery as follows:—" When a current of water is flowing down a pipe so as to fill it completely, and its course is

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suddenly arrested, the energy stored in the water expends itself partly in stretching the material of the pipe, partly in compressing the water, and partly in compressing the air contained in the water. All three

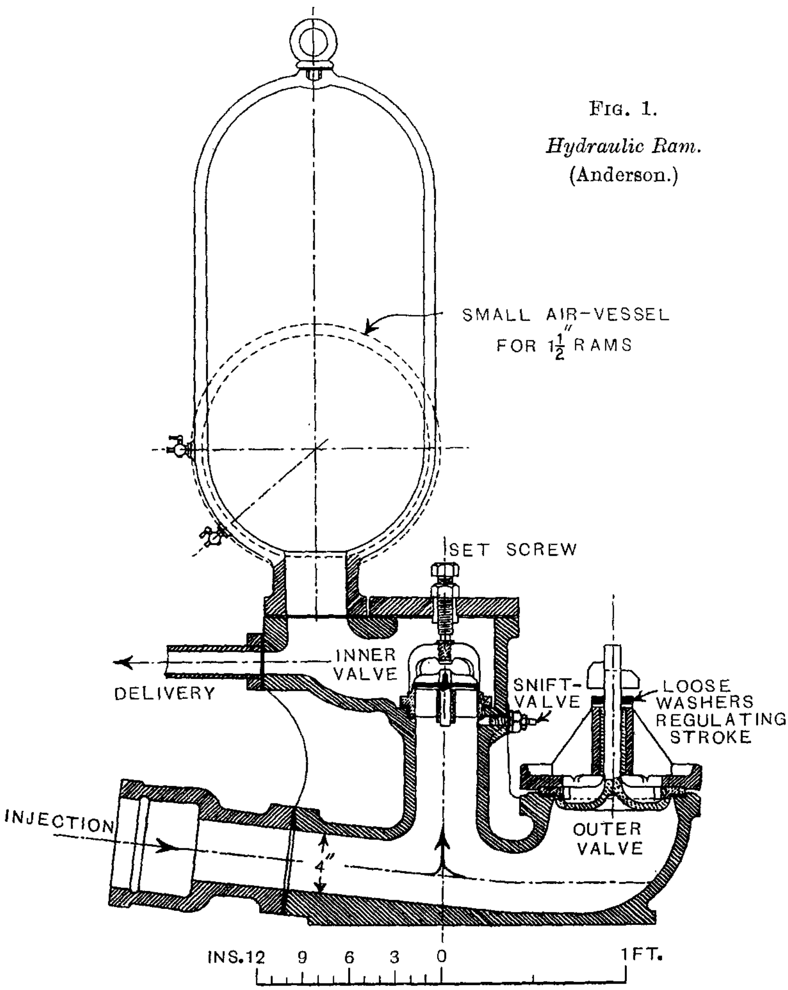


FIG. 1.

Hydraulic Ram.
(Anderson.)

substances are highly elastic and consequently, when strained suddenly, recoil and tend to cause the water to rebound just like one elastic solid rebounds from impact with another." The water is thus for a short time under considerable pressure; so that, if a small hole is made in the pipe at or near the bottom, it will squirt out with great force till the above described reaction takes place.

The first idea of utilizing the principle upon which the action of this machine is based, occurred to one Whitehurst, a clockmaker of Derby, in the year 1772; and he is said to have made and fixed an apparatus to supply water to a brewery in Oulton, Cheshire. A description of the Whitehurst apparatus, which was not automatic, will be found in Morin's "Machines et Appareils destinés a l'Élévation des Eaux," published in Paris in 1863. Twenty-six years later—in 1798—the celebrated French Engineer, Montgolfier, by the substitution of an automatic valve for the hand-cock required with the Whitehurst device, converted the latter into a practical machine, which was introduced to England by James Easton, the founder of the firm of Easton and Amos which subsequently became Easton and Anderson.

There are two ways (which may be termed A and B) of calculating the efficiency of a ram :—

(A) Suppose H to be the height from which the water falls to the ram, and H^1 the height above the supply water level of the point to which it is delivered plus any allowance for friction. Then the height of the delivery point above the ram will be $H + H^1$. Similarly if Q be the quantity of water which flows away from the outer valve, and Q^1 the quantity delivered, then the quantity supplied to the ram will be $Q + Q^1$. In the experiments the efficiency was calculated by this formula :—

$$\text{Efficiency per cent} = \frac{Q^1 (H + H^1)}{(Q + Q^1) H} \times 100.$$

The quantity $Q + Q^1$ is of course obtained when the supply entering the fall pipe is measured.

(B) This method employs the formula :—

$$\text{Efficiency per cent} = \frac{Q^1 \times H^1}{Q \times H} \times 100.$$

Here the quantity Q is given at once if the water flowing from the valve is measured and not the total supply, but it can of course be obtained from the total supply by deducting the quantity delivered. An example may be given of the two methods which shows that the results differ somewhat. A 4-inch "Anderson" ram used a total of 39·51 gallons per minute, and delivered 1·323 gallons per minute to a height of 258 feet, the fall being 13 feet.

Efficiency per cent. by A = 66·4 and by B = 65·2. When the efficiency is calculated by method A, the ratio of height to which water is delivered plus friction (which will in future be called "lift") to the fall is $\frac{H + H^1}{H}$, and by method B — $\frac{H^1}{H}$; therefore the latter figure is always one less than the former. Thus in comparing the efficiencies by the two methods, the ratio R of method A should be compared with the ratio R — 1 of method B.

The main components of a hydraulic ram are :—

The outer or automatic valve.
The inner or delivery valve.
The air-vessel.
The snift or air-valve.
The main casting or body.
The fall pipe.

The Outer Valve.—Experiments were made, keeping other conditions as constant as possible, with a fall pipe 73 feet long, and height of fall 23 feet, against delivery heads, having the ratios of 4, 6, 8, and 10 times the fall. Though there were discrepancies, the general results justified the following conclusions :—

(1) The lighter the valve the higher the efficiency, especially with the longer strokes of the valve, namely : $\frac{3}{8}$ inch, $\frac{1}{2}$ inch, $\frac{3}{4}$ inch and 1 inch.

(2) The lighter the valve the less water is delivered. Exceptions to this were found with the longer strokes of the valve against ratios of heads of 8 and 10 to 1.

(3) The lighter the valve the higher is the number of beats per minute. There were some exceptions to this with the shorter strokes of $\frac{1}{8}$ inch and $\frac{1}{4}$ inch.

It was found, as might be expected, that there is a minimum ratio of lift to fall at which an ordinary ram will not work, and it is usually somewhere about 4 to 1.

It is easy to understand that, if the energy can dissipate itself freely by driving water into the air-vessel against a small resistance, there may be insufficient remaining to bring about the automatic action of the valve, and therefore the ram will cease working. This is also demonstrated by the fact that when starting a ram to work with the delivery pipe empty so that there is but little resistance to the flow of water into the air vessel, it is necessary to operate the outer valve by hand several times until the air-vessel and pipe are charged sufficiently to give the required resistance to enable the valve to work automatically. It is however possible to make a ram work at a lower ratio of lift to fall, even down to below 2 to 1, by the device of putting a spring on the outer valve tending to open it. Table 1 gives the figures obtained from tests on a 4-inch Anderson ram. The reason the efficiency of the middle series is so much better than the others is that the area through the inner valve was greater. This will be dealt with later on when considering the inner valve. In the last set the outer valve had a shorter stroke, and this explains the better efficiency compared to the first set, as the area of the inner valve was the same in both.

The result of many experiments upon the effect of varying the stroke of the outer valve within reasonable limits, has been to formulate the general rule that increasing the stroke increases the quantity of water delivered but reduces the efficiency, and vice versa ; as shown in the first and third sections of Table 1, though there have

TABLE 1.

4-inch "Anderson" Ram, about 13 feet Fall, Pipe 72 feet long working at Low Ratios of Lift to Fall.

Stroke of Outer Valve.	Water delivered. Gallons per Min.	Ratio of Lift to Fall.	Number of Beats per Min.	Efficiency.	Remarks.
Inch.				Per cent.	
$\frac{5}{8}$	14·40	2·08	49	67·5	Spring on Outer Valve.
,,	10·46	2·86	58	69·5	,, ,,
,,	8·37	3·80	60	70·8	,, ,,
,,	6·20	5·50	66	77·7	No Spring on Valve.
,,	13·43	2·88	56	84·0	Spring on Outer Valve.
,,	9·80	3·79	62	80·0	,, ,,
,,	7·66	4·74	62	85·6	,, ,,
,,	6·31	5·70	64	83·5	No Spring on Valve.
$\frac{3}{8}$	12·85	1·87	62	75·6	Spring on Outer Valve.
,,	8·37	2·80	76	78·4	,, ,,
,,	6·52	3·75	81	77·1	,, ,,
,,	4·05	5·57	88	82·1	No Spring on Valve.

been, as usual, exceptions to this. The rule adopted for fixing the best normal stroke of the valve for practical purposes, was to make it that in which the area through the outer valve was equal to the area of the fall pipe. Then, by lengthening the stroke within reasonable limits, a larger delivery of water could be obtained but with the sacrifice of efficiency, which in many cases would not matter, and by shortening it the delivery would be reduced but the efficiency improved. If, therefore, a ram was required to give the

TABLE 2.

Comparative Efficiencies of Rams with Ball and Mushroom Inner Valves.

Stroke of Outer Valve.	Ratio of Lift to Fall.	Ball Valve. Weight $13\frac{3}{4}$ oz.	Mushroom Valve $\frac{1}{8}$-inch Stroke.	
			Weight 11 oz.	Weight $4\frac{1}{4}$ oz.
Inch.		Per cent.	Per cent.	Per cent.
$\frac{1}{4}$	4	70·9	73·6	75·3
,,	6	66·5	68·9	68·9
,,	8	62·7	62·8	60·4
$\frac{3}{8}$	4	65·5	69·8	71·9
,,	6	66·0	69·0	67·4
,,	8	61·1	63·6	61·9
,,	10	53·0	59·9	58·4

largest possible delivery with a limited supply of water, it would be an advantage to put in a large ram and give it a short stroke; or if there was abundance of water, a small one with a long stroke might answer the purpose and would be cheaper.

The Inner Valve.—The results of tests to determine the relative efficiencies of ball and mushroom inner valves are given in Table 2. It will be seen that, with one exception, the mushroom-valve gave the better result, and the weight of it did not seem to be of great importance. The lighter valve appeared to suit the lowest ratio best, and the heavier the higher ones. With regard to the stroke and area of the inner valve, it has been found good practice to allow one square inch of area through the valve for every gallon of water to be delivered per minute. Table 3 gives the results of tests with a graduated stroke of inner valve, maintaining the aforesaid rule as to area.

TABLE 3.

4-inch "Anderson" Ram, about 13 feet Fall, Pipe 72 feet long. Efficiencies with Increasing Ratios of Lift to Fall and Graduated Stroke of Inner Valve.

Stroke of Outer Valve.	Stroke of Inner Valve.	Total Water used. Gallons per Minute.	Water delivered. Gallons per Minute.	Ratio of Lift to Fall.	Number of Beats per Minute.	Efficiency.	Average Efficiency.
Inch.	Inch.					Per cent.	Per cent.
$\frac{5}{8}$	0·50	44·72	9·57	3·89	64	83·2	84·1
,,	0·50	44·94	9·57	4·00	64	85·1	
,,	0·30	43·89	6·20	6·00	66	84·7	84·0
,,	0·30	45·45	6·38	5·94	67	83·4	
,,	0·25	43·13	4·50	7·98	68	83·2	86·0
,,	0·25	40·64	4·44	8·12	66	88·7	
,,	0·15	40·53	3·38	9·93	69	82·7	82·6
,,	0·15	40·29	3·31	10·04	68	82·6	
,,	0·10	36·35	2·46	11·88	65	80·4	79·0
,,	0·10	36·30	2·34	12·05	65	77·6	
,,	0·10	35·90	1·82	14·03	66	71·0	70·6
,,	0·10	36·30	1·82	14·02	66	70·3	
,,	0·075	41·33	1·73	16·10	70	67·4	66·8
,,	0·075	41·29	1·69	16·13	71	66·2	
,,	0·05	42·73	1·59	18·07	72	67·5	67·0
,,	0·05	42·50	1·56	18·10	72	66·5	
,,	0·05	39·70	1·309	19·90	69	65·6	66·0
,,	0·05	30·51	1·323	19·84	70	66·4	

NOTE.—In the first three experiments the outer valve was fitted with a spring to assist in opening it at the low ratios of lift to fall.

The Air-Vessel.—In practice, a ram will not work without an air-vessel. It is easy to appreciate that the water in a long delivery pipe cannot be stopped and started, say, at from 20 to 200 times a minute, and that it must be kept flowing steadily at a uniform rate ; a condition which depends entirely upon the satisfactory functioning of the air-vessel. A most important point is, of course, to keep it properly charged with air. Certain waters in passing through the ram are found to give off air in sufficient quantity to keep the vessel charged. Where, however, water has to be used which does not possess such a property, some method of supplying air must be adopted, such as the "Snift valve." An interesting attempt was made at the suggestion of Dr. Anderson (as he then was) to use cork instead of air for the elastic medium, and so get rid of the difficulty of keeping the air-vessel charged. The experiments gave promising results at first, but it was found that by degrees the cork became water-logged, that is to say the cells became gradually permeated by and at last filled up with water, so that it ceased to act as required and the idea had to be given up.

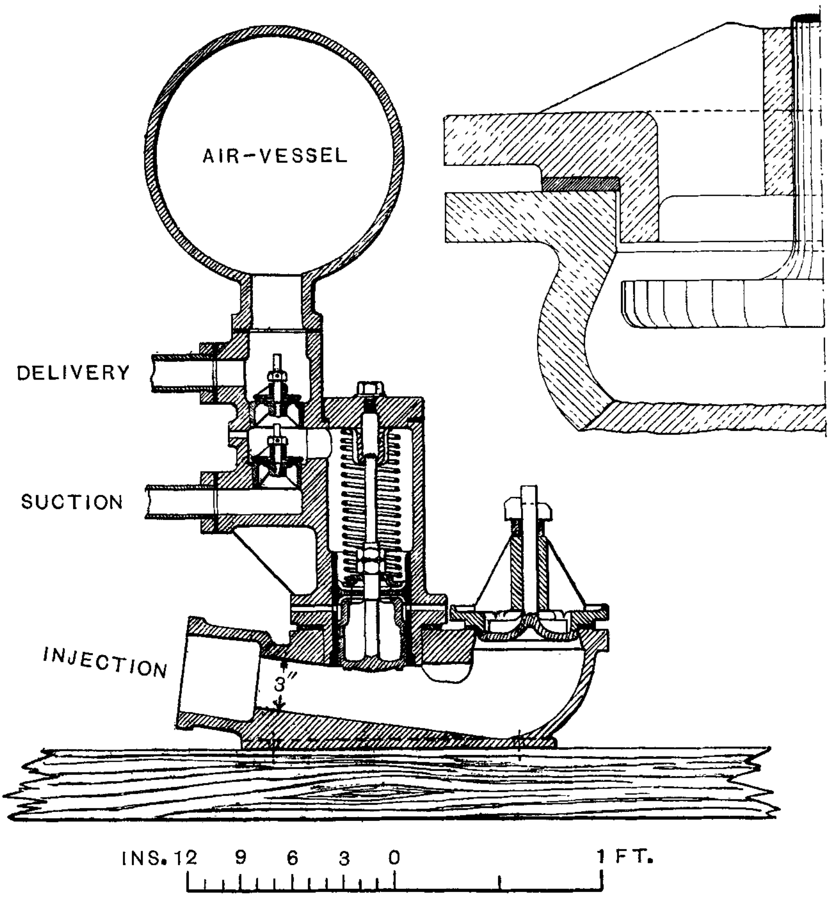
The Snift-Valve.—The function of this valve is to keep the air-vessel supplied with air. It is a small valve opening inwards into the body of the ram usually just below the inner valve. When the reaction takes place and a slight vacuum is momentarily formed in the body, a whiff of air is drawn in through the snift-valve, and finds its way at the next beat of the ram into the air-vessel, the snift-valve of course closing again under the pressure.

The Body.—The great object to be attained is rapid closing of the valve, and anything which tends to retard this will cause loss of efficiency. In a badly shaped body there may easily be eddies in the water which will have such an effect. The Author's experiments have shown that the area of the annulus between the edge of the valve and the body should be made rather less than that through the valve itself, so that the water should have a higher speed locally, and thus tend to close the valve rapidly. Fig. 2 gives a sketch of the half-section of the ram body and valve showing this contracted area. Table 4 (page 346) gives the efficiencies obtained from various published Tables and formulæ, which may be taken fairly to represent general practice, set out in parallel lines with those of the 4-inch Anderson ram.

Some of the Tables and formulæ do not make it clear upon which method of calculating the efficiency they are based. In such it has been assumed that the B method has been used, and the comparison has been made by using the ratio = R – 1. For example, taking the ratio 8 as given in the top line of Table 4, the efficiency in the third line is 68 per cent, which in Hett's Table is that for a ratio of

FIG. 3.—3-*inch Hydraulic Ram for working with Dirty Water.*

FIG. 2—*Showing shape of Body of Ram* (Anderson) *at Outer Valve.*



7 to 1. His efficiency for 8 to 1 is 63 per cent, so that the higher figure has been used for comparison which is on the safe side. The experiments with the Anderson ram were not continued beyond a ratio of 20 to 1, because the fall being about 13 feet, the delivery

TABLE 4.—*Efficiencies of 4-inch "Anderson" Ram compared with those given by various Tables and Formulæ.*

Ratio of Lift to Fall.	4	6	8	10	12	14	16	18	20	—
Anderson 4-inch Ram	84·1	84·0	86·0	82·6	79·0	70·6	66·8	67·0	66·0	No ratio at which Efficiency is zero has yet been reached.
Table given in 1877 by C. L. Hett	—	79	68	56	49	41	34	27	20	Efficiency falls to zero at 27 to 1.
Table in "Molesworth's Pocket Book," 1918	—	72	62	50	43	35	28	20	15	Efficiency falls to zero at 26 to 1.
Some Efficiencies from "Kempe's Year Book"	85 (3·9)	75 (6·38)	67 (7·65)	—	35 (12)	—	—	—	18 (19·6)	Figures in brackets are the actual ratios.
From "Mark's Handbook," American	72	61	52	—	37	—	25	—	14	Efficiency falls to zero at 26 to 1.
Formula—"Molesworth's Pocket Book," 1918 Efficiency = $1 \cdot 12 - 0 \cdot 2\sqrt{H \div h}$	77	67	59	52	46	40	35	30	25	Efficiency falls to zero about 31 to 1.
Daubisson's Formula from "Molesworth." Efficiency = $1 \cdot 42 - 0 \cdot 28\sqrt{H \div h}$	94	80	68	58	49	41	34	27	20	Efficiency falls to zero about 26 to 1.

head would be about 260 feet, and it was not thought wise to go higher; but with a lower fall, 4·75 feet, a 4-inch ram in actual use was tested with a throttled cock and pressure-gauge up to a ratio of 46·3 to 1 when the efficiency was 44·3 per cent.

Particulars have also been kindly supplied by Mr. J. R. Easton, a grandson of the original introducer of the Montgolfier Hydraulic Ram into this country, of some tests made upon Anderson rams in actual work, as follows:—

4-inch ram: 20 feet fall, 364 feet lift, 18·2 to 1 ratio. Efficiency 71·4 per cent, and with shorter stroke of outer valve 67·7 per cent.

4-inch ram: 12·4 feet fall, 142 feet lift, 11·5 to 1 ratio. Efficiency from 72 to 81 per cent, with different strokes of outer valve.

1½-inch ram: 11 feet fall, 70 feet lift, 6·3 to 1 ratio. Efficiency 76·4 per cent.

2-inch ram: 5·5 feet fall.

100 feet lift,	ratio	18 to 1.	Efficiency	53	per cent.
140 ,,	,,	25 ,, 1.	,,	50·6	,,
180 ,,	,,	33 ,, 1.	,,	48·7	,,
230 ,,	,,	41 ,, 1.	,,	53·0	,,
320 ,,	,,	58 ,, 1.	,,	23·4	,,

These figures indicate that, so far, the point of zero efficiency has not been reached with the Anderson ram. For practical use relating to such rams Table 5 (pages 348–9) has been prepared in which the efficiencies assumed and considered safely obtainable up to ratios of 20 to 1 were used as the basis. Calculations were then made of the amount of water used for progressive deliveries from ½ gallon to 7 gallons per minute at each ratio from 4 to 20 to 1 and the size of ram suitable in every instance was selected. A glance at this gives all the information usually required to meet any particular case.

The Fall Pipe.—A lengthy series of experiments was made to ascertain the best proportion of the length of the fall pipe to the height of fall available. Table 6 (page 350) gives the efficiencies obtained. The inferences to be drawn from this Table are, that the longer the pipe in relation to the fall, the better for both efficiency and capability of functioning of the ram under all ratios of lift to fall up to 24 to 1, and that the shorter the pipe, the smaller the ratio above 4 to 1 at which it will work. Varying the stroke of the outer valve somewhat altered these conclusions. In general, it may be said that the best results are obtainable with fall pipes having a length of from six to ten times the fall.

TABLE 5.—*Showing the working*

Gallons Delivered

Proportion of Lift to Fall.	—	—	½	1	1½	2	2½	3
	4	Gallons used .	—	5·00	7·50	10·00	12·50	15·00
		Size of Ram .	—	1½	1½	2	2	2
	5	,, ,, .	3·20	6·41	9·61	12·82	16·02	19·23
		,, ,, .	1½	1½	2	2	3	3
	6	,, ,, .	4	8	12	16	20	24
		,, ,, .	1½	1½	2	2	3	3
	7	,, ,, .	4·72	9·46	14·18	18·92	23·64	28·38
		,, ,, .	1½	2	2	3	3	3
	8	,, ,, .	5·54	11·11	16·65	22·22	27·76	33·33
		,, ,, .	1½	2	3	3	3	4
	9	,, ,, .	6·34	12·67	19·01	25·34	31·68	38·01
		,, ,, .	1½	2	3	3	4	4
	10	,, ,, .	7·24	14·50	21·74	29·00	36·24	43·5
		,, ,, .	1½	2	3	4	4	4
	11	,, ,, .	8·20	16·42	24·62	32·84	41·04	
		,, ,, .	1½	3	3	4	4	
	12	,, ,, .	9·22	18·46	27·68	36·92		
		,, ,, .	2	3	4	4		
	13	,, ,, .	10·32	20·63	30·95	41·26		
		,, ,, .	2	3	4	4		
	14	,, ,, .	11·48	23·00	34·48			
		,, ,, .	2	3	4			
	15	,, ,, .	12·70	25·40	37·11			
		,, ,, .	2	3	4			
	16	,, ,, .	13·80	27·60				
		,, ,, .	2	4				
	17	,, ,, .	15·20	30·30				
		,, ,, .	2	4				
	18	,, ,, .	16·66	33·30				
		,, ,, .	3	4				
	19	,, ,, .	18·26	36·50				
		,, ,, .	3	4				
	20	,, ,, .	20					
		,, ,, .	3					

of "Anderson" Rams.

per Minute.

3½	4	4½	5	5½	6	6½	7	Per cent.	
17·50 3	20·00 3	22·50 3	25·00 3	27·50 3	30·00 4	32·50 4	35·00 4	80	Efficiencies upon which Table is based.
22·43 3	25·64 3	28·84 3	32·05 4	35·25 4	38·46 4	41·66 4	44·87 4	78	
28 3	32 4	36 4	40 4	44 4				75	
33·10 4	37·84 4	42·56 4						74	
38·87 4								72	
								71	
								69	
								67	
								65	
								63	
								61	
								59	
								58	
								56	
								54	
								52	
								50	

N.B.—This Table is made upon the assumption that the actual height of Fall does not affect the output of the Ram, or the efficiency, only the proportion that it bears to the height of lift plus the friction of the delivery pipe.

The length of the Fall Pipe may, under ordinary circumstances, be made equal to from 6 to 10 times the height of Fall.

TABLE 6.

Efficiencies of $1\frac{1}{2}$-inch "Owens" Ram with varying lengths of Fall Pipe and Ratios of Lift to Fall. Fall 11 feet in all but the 1 in 28 when it was 6 feet 6 inches. Stroke of Outer Valve $\frac{1}{4}$ inch.

Ratio of Lift to Fall.	Proportion of Fall to Length of Fall Pipe.						
	Vertical.	1 to 2.	1 to 4.	1 to 8.	1 to 12.	1 to 14.	1 to 28.
4	64·0	56·6	78·6	81·3	84·5	79·5	78·6
6	13·0	44·0	70·5	70·7	81·7	79·1	79·5
8	—	—	61·3	66·6	73·4	74·7	86·7
10	—	—	41·7	39·0	69·5	—	78·3
12	—	—	—	34·5	70·2	68·2	75·0
14	—	—	—	—	47·7	44·3	66·9
16	—	—	—	—	23·6	27·6	51·6
18	—	—	—	—	—	25·3	50·0
20	—	—	—	—	—	15·2	49·5
22	—	—	—	—	—	—	27·9
24	—	—	—	—	—	—	27·8

Dirty-Water Ram.—In this type, Fig. 3 (page 345), water from one source of supply may be pumped by using water under a small head from another source. Its name arises from the fact that its usual duty is to pump clear water from a well or spring by means of dirty or contaminated water from some other source, such as a river. Table 7 gives the results of tests, which are a good deal lower than those of the ordinary Anderson ram. It will be observed that the fall pipe was very short compared with the fall.

The Author is indebted to Mr. J. R. Easton, of the firm of Easton, Courtney and Darbishire, of Westminster, for supplying particulars of some tests of rams in service, and also the drawings for the illustrations (Figs. 1 and 3) of his firm's ordinary and dirty water ram respectively.

TABLE 7.

Ram for raising Clean Water by using Dirty Water.
2-inch Fall Pipe 30 feet long, 13 feet 6 inches Fall.

Stroke of Outer Valve.	Depth of Suction.	Ratio of Lift to Fall.	Number of Beats per Min.	Water used. Gallons per Min.	Water raised. Gallons per Min.	Efficiency.
Inch.	Inches.					Per cent.
3/8	72½	4	136	9·23	1·10	47·0
,,	68½	5	132	9·23	0·93	50·0
,,	67½	6	136	9·52	0·90	56·7
,,	66½	7	138	9·52	0·63	46·0
,,	63	8	132	8·82	0·62	56·0
,,	68½	9	134	9·23	0·46	44·0
,,	67½	10	136	8·70	0·41	47·0
,,	63	11	126	7·80	0·27	38·0
,,	63	12	126	7·90	0·23	35·0
,,	63	13	124	7·14	0·20	·36·0
½	66	9·14	96	14·00	0·86	56·0

The Paper is illustrated by 3 Figs.

Discussed in Birmingham on Thursday, 9th March 1922.

Chairman :—Mr. E. C. R. MARKS, *Member of Council.*

[*Abridged.*]

Mr. R. H. PEARSALL said that while he was not in practice as a hydraulic engineer, his father had made important contributions to the subject. The late Mr. H. D. Pearsall had been interested in large rams for hydraulic mining and irrigation, and such rams were limited by the shock on closing the valve. He therefore designed a ram resembling the Anderson ram, in the presence of a rising pipe to the delivery valve plate, but this pipe or chamber was adapted to empty the water and fill with air at each stroke. This air provided a cushion to the water shock, so that the main valve was able to be shut before the pressure in the ram had risen appreciably. In order to prevent the large main valve from hammering on its seat, it was controlled in its motion and operated by pendulum gear, and a small motor. The latter was driven by the air which passed the delivery valve each stroke.

In this way 2-foot diameter rams had been successfully operated, and even larger rams might be made. By extending the air-chamber, the ram might be turned into an air-compressor of very high efficiency, for it had been found that the cold wet air compressor chamber gave a compression more akin to isothermal than to adiabatic. The speaker had the privilege of assisting his father in the design of such a compressor, which was now supplying rock drills in Devonshire, and worked during the War with practically no attention.

Another form of ram was practicable for such work as irrigation, where both fall and lift were small. This was substantially a "U" tube, in which the water oscillated. A valve was provided at the bottom of the "U" through which water flowed to waste, gaining energy in the long or fall leg. Upon closing the valve, the water flowed on up the riser leg and spilt over into the high level channel. The reverse oscillation emptied the riser of water and the stroke was repeated. In all these cases it was possible to calculate and foretell the actions and periods with reasonable accuracy.

The Paper was a valuable record of experiment and did not attempt to analyse the actions taking place. While we restricted ourselves to the small ram, this was probably the right thing to do, but it was not possible in the larger cases where analysis was most important. The difficulties the Author had had to meet were apparent when the results were plotted, for many disturbing factors were seen to prevent the drawing of good curves.

With regard to the length of drive pipe, it was clear that the shock and its losses were largely confined to the ram itself, so that they would not be increased by increase of drive pipe. But the energy in the water would be increased with increase of drive pipe, so that the relative loss was less and the efficiency greater. This would continue to be the case until the greater length of pipe introduced frictions which reduced the efficiency again.

For efficiency the flow forms were important. His father had paid much attention to this, providing divergent forms beyond the main valve with success. It would appear that the weight of the main valve was a dynamical question, depending on the proportioning of the design as a whole. On plotting Table 2 (page 342,) a curious drop in efficiency with low-lift ratio was noted with the higher main valve lift.

Mr. J. R. EASTON said he did not know of any rams at work in Birmingham, but he could remember one at Shifnal, and there were three at Patshull Park (the Earl of Dartmouth's seat) which had been working since 1856.

With regard to the Tables given, the efficiency figures had been deliberately taken on the low side for commercial reasons, so that they could be practically certain that the ram supplied would give the results mentioned. He noted that Mr. Anderson said that the bodies of the rams were left rough as cast,* but it was his (the speaker's) practice to have the bodies machined for about 2 inches below the lip of the outer valve. To obtain the different ratios from 18 to 1 to 58 to 1 with the 2-inch ram mentioned in the Paper, the stop-valve on the rising main was closed, and a bib-cock inserted between the valve and the ram, with a pressure-gauge. By throttling the bib-cock, the amount delivered by the ram under different heads could easily be obtained.

With regard to the durability of the ram, he knew of one which had been at work for over 100 years near Tunbridge Wells, and was delivering water both to the stables and, at a higher level, to the house. Sometime ago the ram would deliver to the stables, and not to the house, and an engineer was called in who advised the expenditure of £150 on a hot-air engine to do the necessary pumping, but eventually the owners got in connexion with his firm, who found that the valve was leaking. On supplying a new valve the ram worked as well as ever, and was still at work after its 100 years' service. He knew of another case of a ram where the valves had not been touched for twenty-seven years, and when they were examined it was found that the ball of the inner valve had nearly cut through the seating. The ram was delivering a third of the water it should have done, but was still working in spite of the bad state of the valves. In another case where a house had changed hands, the purchaser made no inquiries as to where the water supply came from, until after about four years it suddenly

* This was a remark interpolated in the reading of the Paper.

ceased, and then they began to look into matters, and found that they were not supplied by a water company, but by a ram, and that a leaf had got between the valve and seat, which had stopped the ram. This was removed, and the ram worked as well as ever.

With regard to the "dirty-water" type, or compound ram, he knew of a 5-inch ram by Messrs. Green and Carter, of Winchester, with 18 feet fall raising $2\frac{1}{2}$ gallons per minute to a height of 305 feet, working with an efficiency of 64 per cent. Also one with a fall of 40 feet against a head of 150 feet delivering $6\frac{1}{2}$ pints per minute with an efficiency of 60 per cent. All the efficiencies given were obtained under ordinary working conditions.

He produced for inspection the original Montgolfier patent, dated 1816, with the assignment to his grandfather, and the coloured drawings deposited at the same time; also a patent for a compound ram, which clearly foreshadowed the present arrangement of dirty-water ram, though he could not find out that any were made at that time.

Mr. J. P. UDAL said that after what he had heard, he need not question the reliability of the appliance, but he had more than once come across such a ram in South Africa working all by itself in some out-of-the-way rocky gorge, and he would like to know how it was controlled, certainly not by closing the delivery pipe. He wondered whether somebody had to go to the ram, which was often in an inaccessible position, to stop it, or was the surplus water merely allowed to overflow. He concluded that in any case, under such conditions, efficiency was not a material matter. He asked also what was the largest size of ram made.

Mr. A. GOLDIE ENGHOLM inquired what protection was necessary against frost.

The CHAIRMAN (Mr. E. C. R. MARKS) said that he had once stayed at a house in Pembrokeshire where there was one of these rams 300 or 400 yards from the house, and the only trouble was that he had to go there occasionally to take out the dead leaves which choked the ram or held up the valve and prevented its working, because there was not an efficient strainer to keep it clear. He noticed that the Author had said that the ram would not work without an air vessel on the delivery side; he could not understand why this should be, as it would appear to him that the ram ought to work whether there was an air-vessel or not. He raised the question as to the pollution of the drinking water by the dirty water operating the ram, and would like to know whether this did not occur when the piston got leaky, and whether the sanitary inspectors would pass it, if worked by a polluted stream.

Mr. E. W. ANDERSON, in replying, said he quite remembered being present when Mr. Pearsall's father read his Paper* before the Institution of Civil Engineers. He thought his firm had never made rams over 6 inches diameter, and they generally recommended 4-inch rams as the largest desirable size. They had put down as many as eight 4-inch rams, side by side, in preference to putting down one large one. With regard to the old ball-valve, it was no doubt more difficult to repair than the flat valve, but worked satisfactorily though it was not so efficient. A telegram had once been received at the works, "Ram won't work," and on sending over a workman to see what was the matter, he discovered that the stream had run dry, and naturally there was no water wherewith to work it! As to the ram not working without an air-vessel, it would probably beat but would deliver little or nothing, and with regard to the question of frost, he would ask Mr. Easton to reply, as he had had a much greater experience in installing rams.

Mr. EASTON stated it was found that when the ram was put into a pit, and covered over with a wooden cover, it kept running during frosty weather; there was no trouble in that respect.

With regard to the question of the pollution of the drinking water from the impure source by which it was driven, it would be observed that in the compound ram there were two small holes, just over the bottom piston, and below the upper one, through which any polluted water could escape, so that no mingling of the two streams past the upper piston was possible.

[The Paper was further illustrated by some lantern slides, among them an indicator diagram from a ram, and the original Whitehurst and Mongolfier machines.]

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* Proc. Inst.C.E., 1890-1, vol. cvi, page 292.