

Water-pumping Devices

A handbook for users and choosers

Second edition

PETER FRAENKEL

INTERMEDIATE TECHNOLOGY PUBLICATIONS 1997

Contents

FOREWORD	ix
ACKNOWLEDGEMENTS	x
1. INTRODUCTION	1
1.1 Scope and purpose of this book	1
1.2 The increasing importance of irrigation	1
1.3 Irrigation and the 'Energy Crisis'	2
1.4 Small-scale irrigation and development	3
1.5 The choice of water-lifting technique	4
2. WATER LIFTING FOR IRRIGATION	5
2.1 General principles of water lifting	5
2.1.1 Definitions of energy, work, power and efficiency	5
2.1.2 Efficiency of components: the importance of matching	6
2.1.3 Irrigation system losses	6
2.1.4 Flow through channels and pipes	8
2.1.5 Suction lift: the atmospheric limit	14
2.1.6 Draw-down and seasonal variations of water level	14
2.1.7 Review of a complete lift irrigation system	17
2.1.8 Practical power requirements	18
2.2 Outline of principles of small-scale irrigation	23
2.2.1 Irrigation water requirements	23
2.2.2 Net irrigation requirement	23
2.2.3 Gross irrigation requirement	25
2.2.4 Pumping requirement	28
3. REVIEW OF PUMPS AND WATER-LIFTING TECHNIQUES	29
3.1 Principles for lifting and moving water	29
3.2 Classification of water lifts and pumps	29
3.3 Reciprocating and cyclic direct lift devices	31
3.3.1 Watering cans, buckets, scoops, bailers and the swing-basket	31
3.3.2 Suspended scoop, gutters, dhones (or doons) and the counterpoise-lift or shadoof	31
3.3.3 Bucket hoists, windlasses, mohtes and water skips	33
3.4 Rotary direct lift devices	33
3.4.1 Bucket elevators, Persian wheels and norias	33
3.4.2 Improved Persian wheels (zawaffa or jhallar)	35
3.4.3 Scoop-wheels (sakia, tympanum or tablia)	35
3.5 Reciprocating displacement pumps	37
3.5.1 Piston or bucket pumps: basic principles	37

3.5.2	Double acting piston pumps and plunger pumps	43
3.5.3	Pistons and valves	45
3.5.4	Reciprocating pumps and pipelines	47
3.5.5	Reciprocating borehole pumps	51
3.5.6	Hydraulically activated borehole pumps	53
3.5.7	Diaphragm pumps	54
3.5.8	Semi-rotary pumps	56
3.5.9	Gas displacement pumps	56
3.6	Rotary positive displacement pumps	60
3.6.1	Flexible vane pumps	60
3.6.2	Progressive cavity (Mono) pumps	61
3.6.3	Archimedean screw and open screw pumps	61
3.6.4	Coil and spiral pumps	63
3.6.5	Paddle-wheels, treadmills and flash-wheels	66
3.6.6	Water ladders and dragon-spine pumps	66
3.6.7	Chain and washer or paternoster pumps	68
3.7	Reciprocating inertia (joggle) pumps	72
3.7.1	Flap-valve pump	72
3.7.2	Resonant joggle pump	72
3.8	Rotodynamic pumps	73
3.8.1	Rotodynamic pumps: basic principles	73
3.8.2	Volute, turbine and regenerative centrifugal pumps	73
3.8.3	Rotodynamic pump characteristics and impeller types	77
3.8.4	Axial-flow (propeller) pumps	78
3.8.5	Mixed-flow pumps	78
3.8.6	Centrifugal pumps	80
3.8.7	Multi-stage and borehole rotodynamic pumps	83
3.8.8	Self-priming rotodynamic pumps	86
3.8.9	Self-priming jet pumps	89
3.9	Air lift pumps	92
3.10	Impulse (water hammer) devices	92
3.11	Gravity devices	93
3.11.1	Syphons	93
3.11.2	Qanats and foggara	94
3.12	Materials for water-lifting devices	97
3.12.1	Ferrous metals	97
3.12.2	Non-ferrous metals	99
3.12.3	Timber	100
3.12.4	Plastics	100
3.13	Summary review of water-lifting devices	107
4.	POWER FOR PUMPING	108
4.1	Prime movers as part of a pumping system	108
4.1.1	Importance of cost-effectiveness	108
4.1.2	Transmission systems	111
4.1.3	Fuels and energy storage	114
4.2	Human power	114
4.2.1	Human beings as power sources	114

4.2.2	Traditional water-lifting devices	117
4.2.3	Handpumps	119
4.2.4	Handpump maintenance	124
4.3	Animal power	125
4.3.1	Power capabilities of various species	126
4.3.2	Food requirements	126
4.3.3	Coupling animals to water-lifting systems	126
4.4	Internal combustion engines	131
4.4.1	Different types of i.c. engines	131
4.4.2	Efficiency of engine powered pumping systems	136
4.5	External combustion engines	141
4.5.1	Steam engines	142
4.5.2	Stirling engines	144
4.6	Electrical power	146
4.6.1	Sources and types of electricity	146
4.6.2	AC mains power	147
4.6.3	Electric motors	149
4.6.4	Electrical safety	150
4.7	Wind power	150
4.7.1	Background and state-of-the-art	150
4.7.2	Principles of wind energy conversion	155
4.7.3	The wind resource	170
4.7.4	Windpump performance estimation	176
4.8	Solar power	180
4.8.1	Background and state-of-the-art	181
4.8.2	Principles of solar energy conversion	182
4.8.3	The solar energy resource	191
4.8.4	Solar pump performance estimation	192
4.9	Hydro power	196
4.9.1	Background and state-of-the-art	196
4.9.2	Use of turbines for water lifting	199
4.9.3	The hydraulic ram pump (or hydram)	201
4.9.4	Water-wheels and norias	208
4.9.5	Novel water-powered devices	210
4.10	Biomass and coal (the non-petroleum fuels)	213
4.10.1	General description	213
4.10.2	The use of solid fuels	216
4.10.3	The use of liquid biomass fuels	222
4.10.4	Gas from biomass: biogas	224
5.	THE CHOICE OF PUMPING SYSTEMS	231
5.1	Financial and economic considerations	231
5.1.1	Criteria for cost comparison	231
5.1.2	Calculation of costs and benefits	232
5.1.3	Relative economics of different options	240
5.2	Practical considerations	247
5.2.1	Status or availability of the technology	247
5.2.2	Capital cost versus recurrent costs	249

5.2.3	Operational convenience	249
5.2.4	Skill requirements for installation, operation and maintenance	250
5.2.5	Durability, reliability and useful life	250
5.2.6	Potential for local manufacture	251
5.3	Conclusion	251

REFERENCES	252
------------	-----