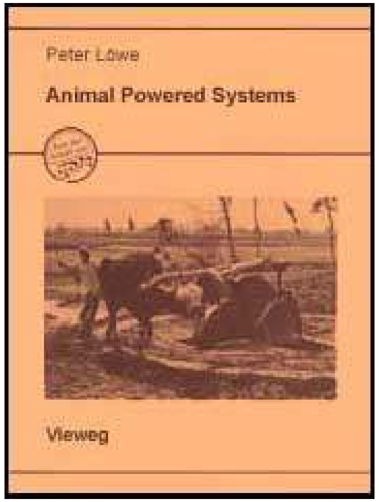
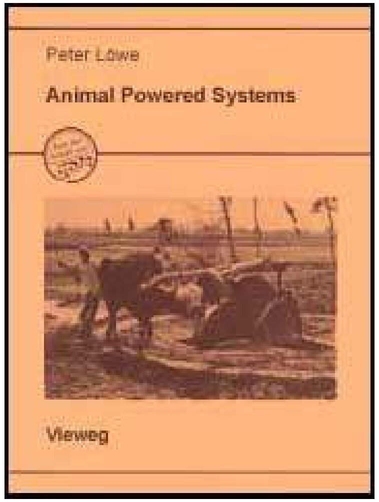


Animal Powered Systems (GTZ, 1986, 60 p.)



Animal Powered Systems (GTZ, 1986, 60 p.)

An alternative approach to agricultural mechanization.

Peter Lwe.

A Publication of the Deutsches Zentrum fr Entwicklungstechnologien - GATE, a Division of the Deutsche Gesellschaft fr Technische Zusammenarbeit (GTZ) GmbH - 1986

The Author:

Dipl.-Ing. Peter Lwe was born in 1951. Studied engineering in Aachen and development economics in Paris. Research work for the Federal Ministry of Cooperation. From 1979 to 1982 GATE's responsable for French speaking Africa. Now working as a consultant and research fellow in ethnology and history of technology.

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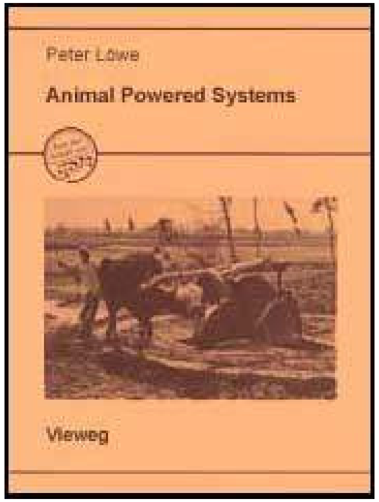

Animal Powered Systems (GTZ, 1986, 60 p.)

8. Animal Power plus Local Handicrafts

The most attractive fields of application for animal-power technology lie in subsistence agriculture and, thus, in areas that have as yet had only superficial contact with industrial technology. The only technical infrastructure that can actually reach the potential user of animal-power technology in such areas is that of the local handicrafts. The following considerations are intended to emphasize their potentially decisive role in the introduction of animal-power technology. The most important demand on technologies serving the field of "assured subsistence" is high operational reliability. Efficiency is a purely secondary requirement. Operational reliability is the very forte of traditional technologies. A traditional water-raising facility, for instance, can quickly be repaired by either the user himself or a local craftsman, but the inability to prevent or remedy the failure of a diesel pump can jeopardize weeks of work. Under certain circumstances, it could even threaten the livelihood - or very existence - of those who depend on it to work.

Just like any other technical innovation earmarked for use in the field of assured subsistence, the animal power, too, will only stand a chance of gaining wide acceptance, if a high degree of operational reliability is guaranteed. A high degree of functional reliability can be achieved by reducing the probability of a breakdown (failure probability) or by increasing the probability of successful repair. While both of those alternatives are possible, they lead in opposite directions when it comes to choosing the type of new technologies. Assuring functional reliability by reducing the chance of outage usually goes hand in hand with a drastic increase in the monetary value (= price) of the machine. In other words, built-in reliability increases the initial cost. If the desired degree of reliability is to be achieved by less capital-intensive means, the only good option is to increase the probability of successful repair. And that, in turn, can only be done by ensuring both that the time lag between breakdown

'and repair is short, and that the cost of repair is moderate.

Then, after only a few years of service, a minor breakdown that the users could not repair on their own effectively took the pump out of commission - long before the end of its theoretical service life. Norias are, by contrast, prone to frequent breakdowns and of low efficiency, but the users can build and repair them with no outside help (industrial inputs), so that - in the long run - they are more "reliable" than commercial models. (They've also been around for hundreds of years!) Thus, the main challenge in the development of new types of animal powers is to come up with designs that combine the advantages of industrial and handicraft technologies, whereby cooperation with local craftsmen is, of course' vital and indispensable. The fact that "assured subsistence" and the provision of essential needs are included in the scope of objectives of developmental cooperation necessitates close attention to the problems of intercultural communication in the project context. With regard to teamwork between development experts and local craftsmen, such problems are further complicated by basic differences in the "mentalities" of craftsmen and engineers. While craftsmen learn new techniques by progressing from outward appearances to the intrinsic relevance, engineers and scientists tend to proceed in the opposite direction. Local craftsmen do not assimilate innovation and technology transfer by studying technical drawings, but through the gradual succession of watching, working together, imitating and, finally, creatively modifying. The nature of animal power as a typical hen dicraft technology is pointed out in Uhland's "handbook for practical-minded machine builders", published in 1899: "In designing an animal power, theoretical calculations are normally dispensed with altogether, because they are of little value. and because the types that have evolved on a practical basis serve as better models for new designs than could ever be arrived at by way of inherently unreliable mathematical determinations." The described line of

causality also applies to the case at hand. Assuming that a certain type of animal power is firmly embedded in the handicraft-technical culture of a region other than the one for which its introduction is envisioned, a temporary exchange of craftsmen could well be the most economical means of effecting the technology transfer. The same is true of numerous other traditional-type water-raising systems. The scope of cooperation and assistance promised in the introductory section of this booklet includes the sounding out and potential fosterage of such unconventional approaches. Handicraft work must by no means be or remain free of all industrial inputs. On the contrary, some handicraft products are only possible due to the availability of certain industrially produced components, be it a relatively complicated mass-produced article like an automobile tire for the runner of an animal-power, or a ball bearing, or any number of hardware articles and accessories such as nuts and bolts, screws, steel cables or plastic tubing., In some countries, the manufacture of animal-drawn wagons and carts has already taken on more intensive forms of specialization, e.g. in which the domestic industry supplies the wheels and axles, and the craftsmen build the bodies. In the case of an animal power, the labor breakdown could consist of: bearings, shafts and any cast-iron gear wheels from the industry, and the rest from craftsmen. While the incorporation of scrap parts would be conceivable during the initial phases of a propagation program, limited availability of the requisite parts would be a major handicap for long-term projects.

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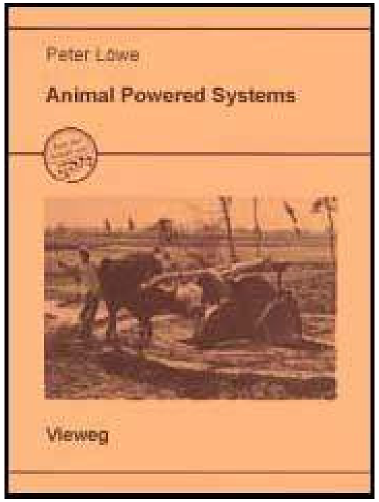
Animal Powered Systems (GTZ, 1986, 60 p.)
9. Fifteen Comprehensive Theses for the Propagation of Animal-Power Technology



(introduction...)
References

Animal Powered Systems (GTZ, 1986, 60 p.)

9. Fifteen Comprehensive Theses for the Propagation of Animal-Power Technology

1. The animal power is a possible - often the sole feasible - alternative to manual labor, the main precondition being that the potential user has already gained experience with or, at least, already has access to draft animals.

2. For substantial and economic reasons, it is recommended that measures for the propagation of animal-power technology should not be isolated but integrated in advisory agricultural programs.

3. The animal power is especially suitable for the expansion and intensification of subsistence farming.

4. Depending on the envisioned application, the availability of draft animals and the efficiency of the animal power, a single animal-powered system can replace the work of 3 to 30 people.

5. In an agricultural environment, animal powers can be used for at least the following purposes: raising water, grinding grain and fodder, chopping, threshing, husking and stripping corn, shelling peanuts, crushing sugar cane, pressing oil-producing plants, grating cassava and cocoa, lifting loads (e.g. in well building), mixing and shaping clay bodies (bricks and banco), etc.

6. The local-market availability of handoperated or mechanically driven machines that could also be suitable for use in animalpowered systems is a matter for case-by-case clarification, particularly with regard to robustness, which can only be determined in actual practice.

7. The user himself must normally bear the initial capital outlay for an animal power. The minimal financial resources of subsistence farmers limit the use of industrial inputs to the absolutely minimum requirement.

8. The prime criterion for subsistence-sector technologies is reliability, not efficiency. Reliability can only be ensured through the participation of local craftsmen.

9. Exchange programs for craftsmen are an adequate approach to the transfer of handicraft technologies. Especially in cases involving craftsmen from different countries and regions, institutions dealing in the transfer of technology are called upon to cooperate.

10. Historical animal powers of industrialized countries or traditional animal powers of other developing countries may serve as patterns for new and advanced models. Cooperation with institutions involved in the colIecting, processing and passing on of relevant information is therefore important.

11. Since animal powers are often operated by children or other persons who are unfamiliar with machinery, safety equipment is a must. Accidents could jeopardize entire propagation programs.

12. Animal powers may be owned and/or operated by individual farmers, cooperatives or public institutions. It would also be conceivable to rent out animal powers or to employ the services of small-scale entrepreneurs for milling, threshing, etc.

13. Since draft animals are usually under the control of the male side of the family most likely the head of the family - animal" power technology may contribute to the marginalization of women and young farmers. The development of animal-powered systems tailored to the needs of those groups (e.g. using donkeys) may help to counter such situations.

14. There are substantial psychological reservations against animal-power technology. Visions of cruelty to animals arouse public suspicion in the donor countries, and its simplicity, seemingly to the point of primitiveness and archaism, has a like effect among the elite of the developing countries.

15. The industrial nations have no direct economic interest in the spread of animal-power technology (no export potential). Nor are any nominal impulses to be expected for the modern economic sector of the developing countries. Thus, it is a precondition for the spread of animal-power technology in subsistence farming that the donor and recipient countries define - and adhere to - a collection of appropriate development goals and planning data.

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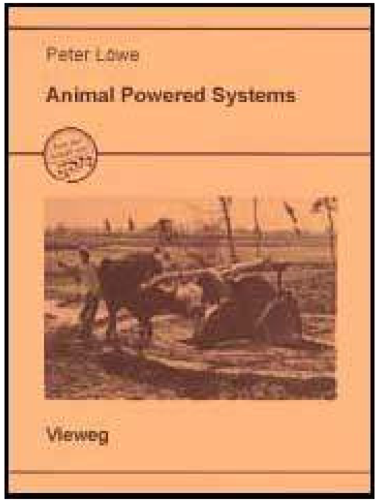

Foreword

The world's oldest form of renewable energy - meaning the muscle power of animals and its utilization in animal-powered systems - is enjoying a special measure of attention within the scope of West German technical cooperation with developing countries. Such systems, which are still referred to in a broad sense as "animal powers" are by no means unknown in the third world. A classic example of an animal-powered system is the "Persian wheel".

Before the advent of the steam engine, animal powers were the only source of mechanical energy (with the exception of hydraulic power and wind power) in Europe, too. Unfortunately, many of the original animal-power inventions have since dropped into oblivion. Even worse: a lot of experience has been irretrievably lost.

The German Appropriate Technology Exchange (GATE) and the agricultural and rural development division of the German Agency for Technical Cooperation (GTZ) are therefore devoting increased attention to animal-power technology. The current pro" gram is intended to determine the extent to which animal-powered systems can be duplicated, modified and reintroduced for special purpose applications. The yield on information, data and experience will be made available to interested parties in the German developmental aid sector. We are proceeding on the assumption that the

historical and traditional forms of animal-powered systems respectively employed in various industrial and developing countries can serve as models for new and advanced versions. Initial work on the development and testing of a "universal power" is already well under way.

In our opinion, animal powers are frequently the best possible alternative - and, often enough, the only feasible alternative - to manual labor. The main prerequisite, of course, is that the potential user is already well-practiced in the use of draft animals. As long as that condition is fulfilled, an animal power would offer a prime opportunity for expanding and intensifying agricultural production or handicraft trade.

This-publication is intended as a contribution towards opening up new fields of application for animal-powered systems. This applies in equal measure to areas in which such systems have not yet been used and to areas of traditional application, where advanced, modernized versions would be of advantage.

Dr. K.-J. Lampe Dr. H.-W. von Haugwitz

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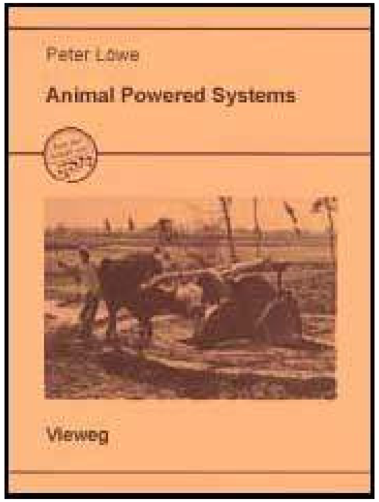

1. Dialogue and Cooperation

This booklet presents a collection of information on the oldest form of "renewable energy": draft animals and their use in animal powers.

The term "animal power" has deliberately been given a comprehensive, generic meaning that refers in general to all technical facilities employing the muscle power of animals for purposes other than soil tilling or transportation and haulage. Accordingly, this includes equipment which does not require the animal to move along a circular track.

The, so to speak, "classic" example of animal power - and the most familiar one in the field of development cooperation - is the "Persian Wheel", a traditional device for raising water. In developing countries, animal powers are also used for a variety of other purposes, most notably for the operation of mills and crushers.

Even in the so-called industrialized countries, the animal power once was practically

the only source of mechanical energy, except water power, until the steam engine was invented. Its range of applications was accordingly wide. While that now offers the advantage of being able to rely on historical patterns for the design of new models, the historical background of animal-power technology may well be its own greatest source of reservations against its present-day propagation in developing countries: the stigma of "grandfather's technology".

By now, many historical applications have lost all practical significance - even in developing countries. Especially the heavy machines of preindustrial Europe have become technically obsolete and can no longer be used economically. If this booklet nevertheless includes illustrations of some of such machines, this has been done in an effort to clarify the structural principles and to serve as a well of ideas for "new" designs and applications.

Be that as it may, it would still be wrong to dismiss the animal power on the whole as "grandfather's technology". In rural areas of developing countries, where animal harnessing is still practiced, electric power is unavailable, fuel for engines is too expensive for numerous purposes, and maintenance facilities are rare, special-purpose animal powers can make good substitutes for or complements to mechanization by motorization.

Unfortunately, much of the information that would be of value in appraising such alternatives cannot yet be included in this booklet. The amount of practical experience gained to date in the field of animal-power technology is still too sparse to permit a comprehensive survey of all potentially interesting applications of the animal power and its respective performance data. Nor are we yet in a position to provide detailed instructions on design and construction.

The, no doubt, most irksome gap is the extensive lack of economic data on the initial and operating costs for animal-powered systems. Neither the historical sources nor the traditional applications studied to date in developing countries, nor the few isolated prototypes that have been installed in recent years have yielded enough information to allow any degree of generalization.

On the other hand, a lot of the information that is either already available or relatively easily accessible on the subject of animal powers has not been dealt with in this booklet, since it would have exceeded the agreed scope and have had a detrimental effect on the overall clarity. It is intended that a more detailed publication will be elaborated at some later date, when - it is hoped - more practical experience has been gathered.

Thus, we were faced with the problem of distilling information on a subject of vast historical, geographical and technical purview, without knowing the real information requirements of the readers and potential users of animal-powered systems. This fact, together with our prime intention of giving the reader an incentive to think over his own personal needs and then design his own adaptations to specific problems of application, has prompted us to give this booklet roughly the character of a - somewhat fragmentary - mosaic. General considerations that can also be applied to the revival of other "indigenous technologies of developing countries" have been included along with detailed profiles of various individual types of animal powers an a thesis-type summary of some generally valid characteristics of animal-power technology and the stumbling blocks to be anticipated with regard to the implementation of such systems.

The animal power is a technological approach that can be adapted to a wide variety of situations. The term also gives expression to the observation that innovations are

always the result of long iterative processes, the success of which is decisively dependent on extensive communication. and feedback between the "supplier" and the "user" of any particular technology. Technological adaptation requires a "collective effort", from the first idea for a solution to a certain technical problem, over its final realization by way of intensive information gathering and the design and construction of prototypes, to its widespread practical application.

GATE, and in particular its "Question & Answer Service", see themselves as the partners of potential users of technology in processes of innovation involving development technologies that have not yet reached the marketing stage, namely technologies to which the usual patterns of adaptation through market mechanisms cannot be applied. This includes animal- power technology This booklet constitutes an invitation to the reader for an exchange of views on the extent to which animal-powered systems could be developed for his own specific purposes. The main target group are those readers who have both the means and the intention of trying animal powers for practical purposes. We are prepared to carry our own share of the burden by performing intensified research related to specific situations, helping in the calculation and design of prototypes, and assigning experts for temporary consulting and advisory functions.

That way, the user will gain a clearer perspective of the innovative risk, though we cannot and do not wish to take away the initiative and relieve the user of his own ultimate responsibility.

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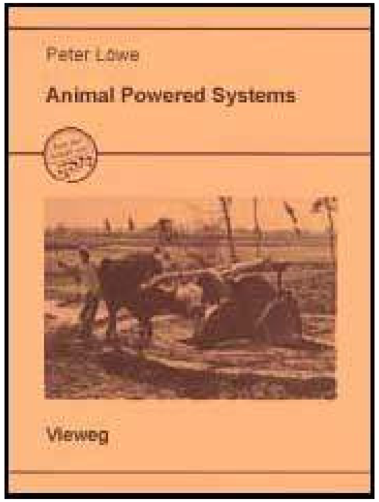


Animal Powered Systems (GTZ, 1986, 60 p.)

2. Rural Energy - Draft Animals - Animal-Powered Systems

The "third-world energy crisis" has already received too much coverage to justify going into detail about it here. The same applies to a discussion of how to cope with the crisis by means of development strategies based on the use of such "renewable energies" as solar power, wind and biomass. There has, however, been a conspicuous gap in such discussions, namely the lack of interest in the utilization of animal power.

This situation could be meaningfully altered by giving more attention to animal-power technology, since it offers possibilities of bringing the "renewable energy" animal power to a more general scope of application above and beyond its present nearly exclusive use in soil tilling, transportation and haulage.

The "third-world energy crisis" actually breaks down into two separate problems with only an indirect link: on the one hand, we have the steadily rising prices for commercial energy, the impact of which primarily affects the modern industrial economies, and on the other hand, there is the factual non-availability of substitute forms of energy for subsistence agriculture, which is still largely dependent on manual labor. The frequent expectation that "renewable energies" should provide alternatives for natural oil, electric power and manual labor - all at once, of course - surely cannot be met by an animal power alone. Draft animals and, in turn, animal-power technology are - with a few exceptions - only of interest for the agricultural sector, where they do, indeed, often constitute the most attractive form of "renewable energy".

Unfortunately, it is difficult to quantify the cost of such renewable energies. Take, for example, Egypt - a classic "animal power land" - with its 300000 to 400000 animal powered water-raising systems ("Saqia"): In much the same manner as their European counterparts did until just a few decades ago, Egyptian farmers still put their cattle to a multitude of uses: for tilling the soil; supplying milk, meat and offspring (calves); acting as an "economic buffer" against the ups and downs of agricultural life; and, of course, driving the family "Saqia". While the expenses involved in draft-animal husbandry can be more or less objectified on the basis of how much it costs to rear, stable, feed and care for a cow, for instance, the share of those costs to be allotted to any particular job can at best only be roughly estimated: there are numerous "opportunity costs" to be reckoned with, such as how much more milk the cow would have given, or how much less it would have eaten, if it had worked only half as hard.

For years now, such questions have fueled a running controversy between "Saqia" advocates and opponents. Both sides keep coming up with evermore elaborating economic analyses to "document" their diametrically opposite views. This is understandable, considering how hard - if not futile - it is to subject polyvalent animal usage to a process of economic analysis.

The historical background of animal-power technology in industrialized countries can certainly only be drawn on to a limited extent in relation to the conditions prevailing in developing countries. Since, however, the animal power remained competitive in Europe and America as long as the tractor had not yet gained general acceptance as a superior soil tiller, a general analogy to the present-day situation in developing countries would indeed appear reasonable.

In some areas, where the use of draft animals is still in the introductory stage, it is often thought that the animals must be put to as many uses as possible in order to make them "pay their keep". In the Sahel Strip, for example, where most draft animals are either left to forage for themselves or turned over to the care of nomads outside of the soiltilling season, animal-power technology could go a long way towards enabling the year-round utilization of such animals. Poor performance due to emaciation or prolonged idleness could be prevented by using the animals to raise water for irrigated horticultures during the dry season. In some eases, certain flanking measures (cultivation of fodder and/or the construction of fodder silos for the dry season) would have to be taken.

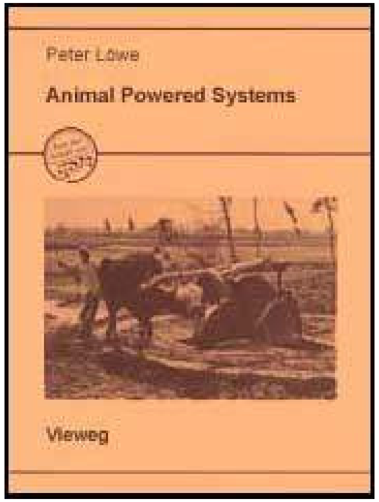
The use and/or ownership of animal powers can be of interest to individual farmers as well as to cooperatives. Another possibility would be to rent animal powers or to have certain steps of refinement such as threshing, grinding, etc., taken care of by self-employed animal- power operators. Such practices are by no means unknown in

developing countries and are not without precedent in European and North-American history.

Rural development projects in Africa aimed at introducing or enhancing harnessing practices present near-ideal opportunities for the simultaneous introduction of animal-power technology. The infrastructure of such projects (consulting, small-loan handling, handicraft promotion, etc.) could be exploited for the purpose of introducing and propagating animal- power technology. That way, the existing infrastructure would be put to a more economically efficient overall use.

This booklet presupposes a working knowledge of the technological and economic aspects of draft-animal utilisation. It is based on the handbook "Animal Traction in Africa" (GTZ Series 120), in which the subject information is conveyed in an up-to-date, concise form.

Like the handbook, this booklet focuses primarily on applications to suit the African situation.



3. Historical Photos and Illustrations

KAISERLICHES PATENTAMT.

AUSGEGEBEN DEN 1. APRIL 1886.

PATENTSCHRIFT

— № 35013 —

48d 5/04

KLASSE 46: Luft- und Gaskraftmaschinen.

A. GRAF und H. HANAUER in WINNWEILER.

Göpel mit Vorrichtung zur selbstthätigen gleichmäßigen Vertheilung der Zugkraft nebst selbstthätiger Peitsche zum Antreiben lässiger Zugthiere.

Patentirt im Deutschen Reiche vom 15. September 1885 ab.

a ist Triebrad, *b* die Zugbäume, an welche die Zugthiere gespannt werden. Die Bäume sind an ihren inneren Enden mit in einander greifenden Halbkreiszahnrädern *c* versehen, welche mit ihrem Centrum in den an dem Triebrade *a* oder, wenn eine Zughülse über dem Rade *a* angebracht ist, an der Zughülse befestigten Bolzen *d* drehbar gelagert sind.

e sind Peitschen, welche in Hülsen mit drehbarem Bolzen *f* befestigt sind. Dieser Bolzen ist mit einer Spiralfeder versehen, sowie mit einem seitwärts gerichteten Arm *g*.

h ist ein im Boden befestigter Pfahl.

i i sind Arme, welche an den Zugbäumen befestigt sind.

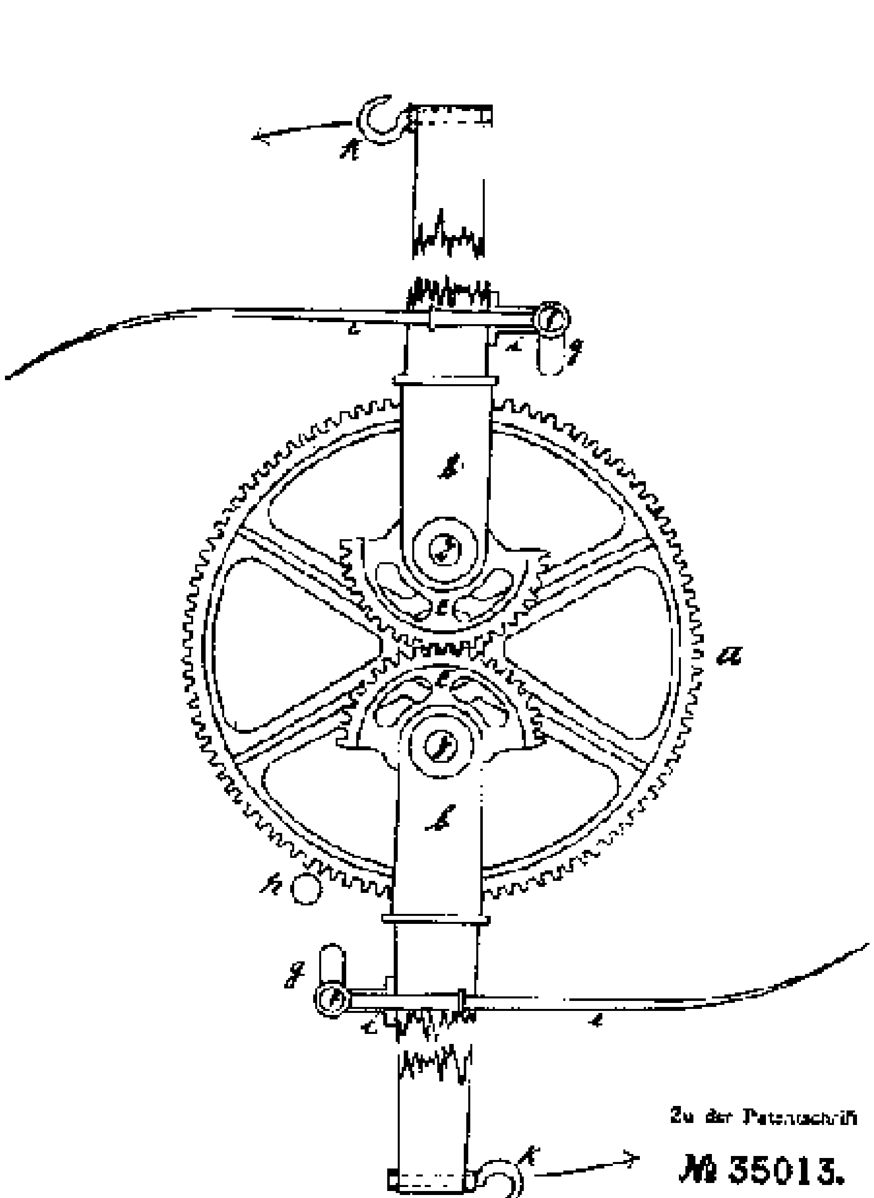
k k sind die Zughaken der Zugbäume.

Die Wirkungsweise ist folgende:

Nachdem die Zugthiere an beide Zugbäume *b b* gespannt sind und eines dieser Thiere durch Vorwärtsgehen Kraft auf den Zugbaum ausübt, wird durch die an den Zugbäumen angebrachten Halbkreiszahnräder der entgegengesetzte Zugbaum rückwärts bewegt, wodurch das daran befindliche Thier genöthigt wird, ebenfalls gleiche Kraft auf den Zugbaum auszuüben. Wird eines der Thiere bei der Arbeit lässig, so hat es trotzdem dieselbe Kraft auszuüben und wird bei zu weitem Zurückbleiben durch die Peitsche *e* angetrieben. Durch das Zurückbleiben wird sich der Arm *g* dem Centrum, also auch dem Pfahl *h* nähern, so dafs der Arm *g* bei noch weiterem Zurückbleiben des Thieres sich mit seinem Ende an den Pfahl *h* anlegt, wodurch die Peitsche mittelst des drehbaren Bolzens *f* zurückgezogen, also von dem Thiere entfernt wird; gleitet nun der Arm *g* von dem Pfahl *h* ab, so wird die Peitsche durch die Spiralfeder nach vorwärts geschnellt, wodurch das Thier einen schwächeren bezw. stärkeren Hieb, je nach der Federspannung, erhalten wird.

PATENT-ANSPRUCH:

Ein Göpel, an welchem die Zugbäume *(b)* drehbar um aufserhalb des Göpelcentrums angebrachte Bolzen *(d)* angeordnet und durch Zahnradkränze *(c)* an ihren inneren Enden in solcher Weise verbunden sind, dafs das Zurückbleiben eines Zugbaumes das Voreilen des anderen zur Folge hat und an welchem Peitschen *(e)* beim Zurückbleiben eines Zugthieres durch Anschlag und Feder selbstthätig bethätigt werden.



Zu der Patentschrift

№ 35013.

Fig.: "Power gear with self-acting device for the equalization of tractive forces and self- acting whip for hastening lazy draft animals" (patent no. 35013, German

Imperial Patent Office)

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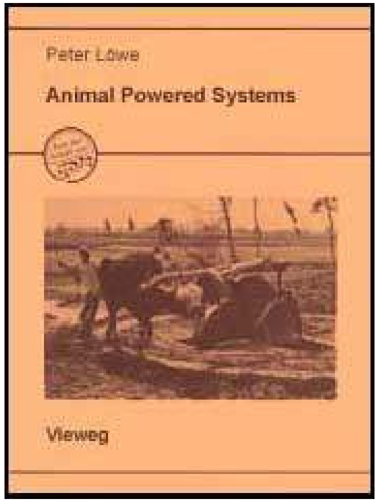

4. Animal Energy-Living Energy

The data stated in pertinent literature on the optimum tractive powers and speeds of different breeds of draft animals vary considerably. For donkeys, 25-40 kp and 0.55-0,7 m/s are usually indicated, for horses 35-80 kp and 0.55-1.1 m/s and for oxen 30-

80 kp and 0.6 - 0.85 m/s. While information on camels is scarce, they seem to have a somewhat higher tractive power and a slightly slower speed than oxen. As a rule, draft animals can be worked for some minutes or even hours at levels exceeding the optimum values, as long as they are allowed to rest for an adequate length of time afterwards in order to regain their full strength.

Since draft animals are living sources of energy, the physical parameters are accompanied by numerous other determining factors, which, however, defy precise description and prediction. In addition to environmental parameters such as temperature, humidity, the time of day and the season, such nonphysical factors include, for example, the animal's age, state of health and momentary mood, between it and the drover, and the work cycle it is expected to cope with.

For example, the maximum tractive-force requirement for plowing is often rated as For example, the maximum tractive-force requirement for plowing is often rated a 1/7 - 1/10 of the animal's weight, whereby the lower value relates to freshly cleared land with soil that still contains roots capable of causing considerable and unforeseeable fluctuations in the amount of tractive effort required. An animal power - even one in which the load varies rhythmically, i.e. foreseeably - never subjects the animal to such pronounced, heavily taxing fluctuations.

The maximum tractive power that can be achieved for a very limited time is stated in the literature as ten times the optimum level (for slowing down from a dead run) down to two or three times the optimum level (for overcoming inertia).

Draft animals harnessed in teams perform at about 10-20% below their optimum standard.

Consequently, doubling the number of draft animals does not equate to a doubling of efficiency. In span labor, both the per-head tractive power and, to a lesser extent, the speed will drop off noticeably.

The situation with regard to the optimum achievable work output is similar to that concerning the ascertainment of the animal's performance level. For European draft horses, the daily work period is taken as 8 to 10 hours, depending on the breed. The optimum daily work output is the product of the number of work hours and the optimum performance level. While the optimum daily work output can sometimes be exceeded, the days required for recuperation will, in the long run, cause the amount of work done under excessive strain to drop below the optimum level.

In historical literature on hauling operations, numerous references can be found to the effect that imponderables such as how well the wagoner understands his horses, how much prudence he exercises in giving them a rest at the proper time and place, and even the "tone of his voice and the bite of his whip", greatly limit the validity of any approximation formula.

For several consecutive hours of overexertion, it was often assumed ("according to Maschek") that the three factors power, speed and daily working time were of identical influence. Accordingly, a 10% increase in tractive power and a 15% rise in speed would necessitate a 25% decrease in daily working time (based on the respective optimum values).

The consequences of short-term overexertion with regard to the daily working time were considered negligible, and it was assumed that a doubling of the tractive effort (e.g. for pulling vehicles uphill) could best be compensated for by cutting the speed in half. It is important to note that only well-trained horses will automatically behave

accordingly. "Young, hot-headed" horses, however, tend to increase their speed beyond the optimum level whenever more tractive effort is expected of them. One of the many tasks of the driver was to prevent such behavior and, hence, the untimely exhaustion of the animals.

The influence of uphill pulling on an animal's tractive power was tentatively described on the basis of the observation that, on a slope of 30° or more, the draft animal needs its entire strength just to move its own weight. It was taken for granted that the tractive effort would decrease proportionally on a more gradual slope (i.e. by one-third for a slope of 10°).

The braking ability of well-trained horses on slopes was assumed to be about half as high as the tractive power. The potential increase in tractive power due to the influence of the animal's own weight on downhill slopes which would constitute an important factor in an analysis of the "Delou" (described later on) - was not investigated, since it was of no interest to the hauling trade.

Consequently, the data to be found in pertinent literature permit only very rough estimates regarding the work output that can be achieved using the appropriate draft animals for animal-power applications. Since animal powers will, as a rule, only be used where an adequate amount of experience has already been gained in the utilization of draft animals for soil-tilling purposes, the empirical data gathered in this field will permit much more accurate assessments of the likely animal-power efficiency levels, and should therefore be given preference over data indicated in the literature.

Despite a scarcity of available data, it may be stated with all certainty that the performance of draft animals in developing countries is considerably lower than the

levels observed in Europe. The tractive power of an African plow horse for example, is rated at 260 W. whereas the old European power unit "1 HP" corresponds to 750 W. or nearly three times as much.

Much the same applies to the daily work period, which amounts to 3 to 6 hours for African horses. Thus, the work output that can be achieved with African horses amounts to only about 20% of the corresponding European standards. As for ox harnessing, the difference is less pronounced, but still significant.

Since the utilization of draft animals in Africa is of very limited tradition, it cannot yet be said to which extent the lower draft-animal performance level is attributable to climatic factors or to the less-than-optimum breeding status of African draft animals.

While the development of a high-performance engine may take years, the breeding of draft animals for European conditions has been- going on since the early Middle Ages: animal energy = living energy.

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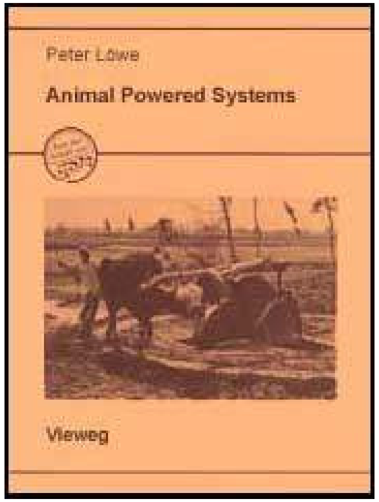
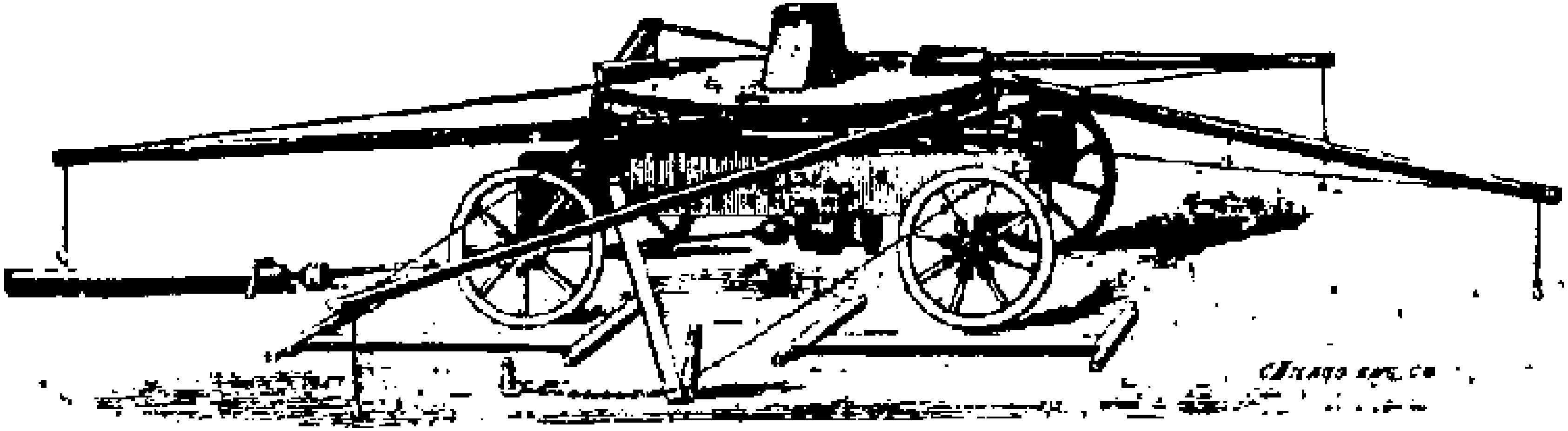
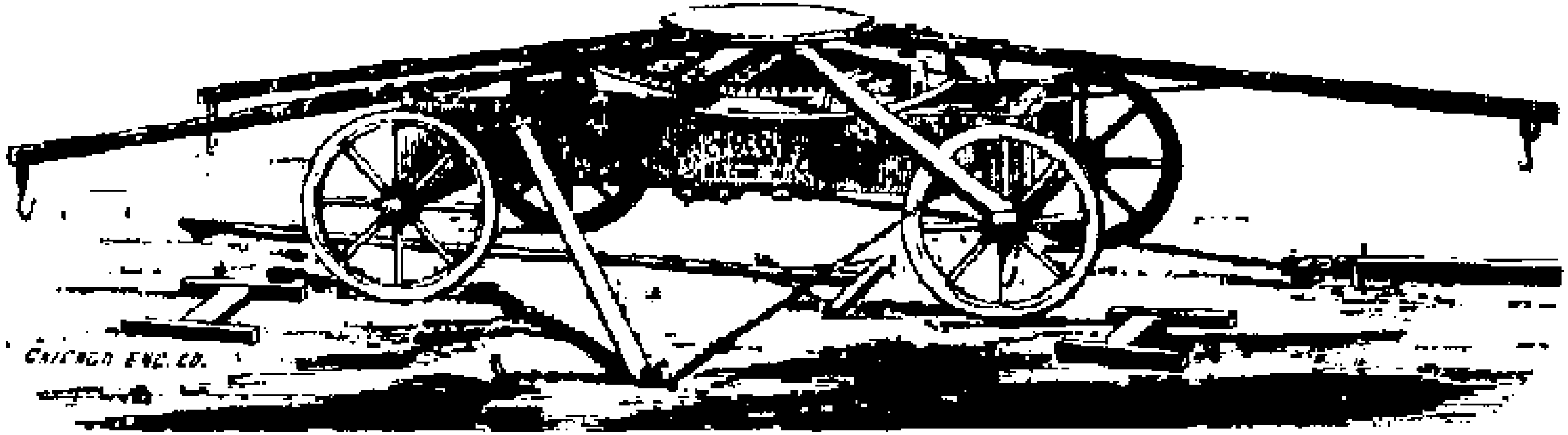


5. Draft Animals: All Work and No Play?

"A Merciful Man is merciful to his beast. Moral: Buy a J.I. Case Horse Power!" Behind that appeal by an American manufacturer of agricultural machinery to the Christian conscience of the American pioneer of 1878 (figure below) lurks a psychological barrier that - more than a century later - could represent an impediment to the propagation of animal- power technology via development projects: whoever uses or recommends the use of an animal power is a potential tormentor of animals. The significance of such suspicions, especially with regard to public interest in the development policies of industrialized countries, should not be underestimated. Time and again, organizations dedicated to the prevention of cruelty to animals have spoken out against the promotion of systems- based on tractive animal power in developing countries.





Fourth Month. 30 Days

APRIL

MOON'S PHASES	Day	Chicago.	Washington.
	D.	H. M.	H. M.
New Moon.....	2	5:34 P. M.	4:06 P. M.
First Quarter.	10	9:04 A. M.	9:46 A. M.
Full Moon	17	0:07 A. M.	0:49 A. M.
Last Quarter.	24	2:43 A. M.	2:25 A. M.

"A Merciful Man, is merciful to his beast."—Moral.—Buy a *J. I. Case & Co. Horse Power.*

The Four-Wheel Woodbury Power has a *reversible* bull wheel; when worn on one side, can be turned over and used on the other.

The Four-Wheel Woodbury Power has larger journals and oil chambers; stronger bull pinions; patent Gear adjuster; babbited centre box.

Fig.: Advertisement by an American animal-power manufacturer (1878)

Add to that the associations with days gone by that animal-power technology can call forth at the drop of a hat. Thoughts of treadmills and slavery crop up. And so, it could happen that the only feasible alternative to one or the other case of slave-like manual labor is rejected without even having been tried.

Do animal powers really just make slaves of poor dumb beasts? Love of animals derives from the knowledge that, in many ways, animals are not unlike human beings. Such insight is most readily acquired through close, daily contact with animals.

Within the framework of Christian morality, man's love and respect for animals grew primarily out of the relationship between beasts of burden and their keepers' and so polemic the remark may sound - that love and respect seem to be disappearing at about the same rate that draft animals are being replaced by factory farming and pointless animal experiments. Anyone who is in some way dependent on the services of draft animals must sooner or later recognize the fact that he can get more work out of them - and increase his own profits - by paying heed to how his animals express their needs, learning to understand their "signals", and trying his best to keep them as contented as he can. This includes proper feeding, grooming and preventive health care as well as the use of harnessing techniques adapted to the needs of the animal and attention to its naturral working habits. A draft animal will feel all the better, the more intensively and conscientiously it is put to work.

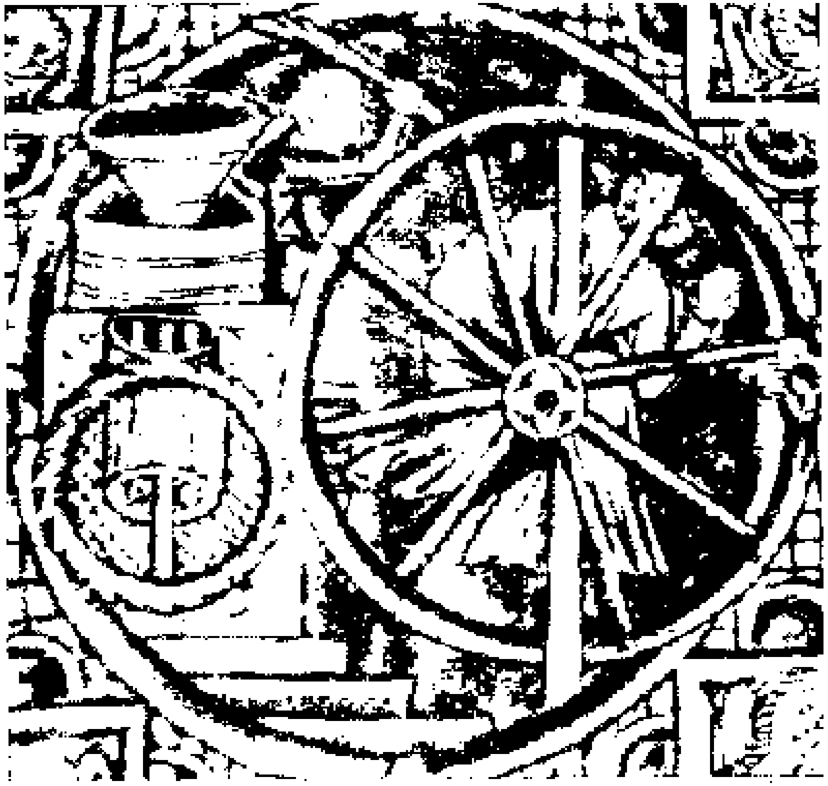


Fig.: "Samson in the treadmill" (16th century)

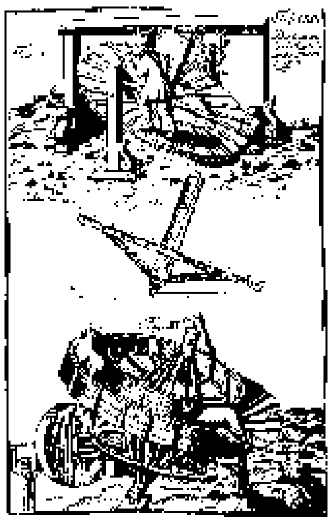


Fig.: 18th-century treading disks

But, what are the needs of a draft animal at work in an animal power? How can its energy best be utilized and, to the extent possible, increased? Due to the circular track that the draft animals are forced to follow in a sweep power, as much as one-half of the animal's normal "straight path" efficiency may be lost due to the slow pace in combination with a waste of strength that is inherent to such systems.

The first way to improve efficiency is to maximize the diameter of the track in order to make the drawbar as long as possible (not less than 3.50 m), though the attainable advantages must be carefully weighed against the increased cost of construction and the lower speed of rotation.

The energy losses in a sweep power can be further reduced by ensuring that the tractive power is tangentially applied to the circular track. If oxen or castles are serving as draft animals, that is relatively easy to manage by securing the drawbar at the animal's withers. In the case of donkeys or horses, a somewhat more complicated harnessing arrangement must be used.

In addition, achievement of optimum performance on the part of a draft animal is also decisively dependent on the selection of an optimum work cadence. In this connection, it is interesting to note that both the Delou and the Persian Wheel - two animal-powered water- raising systems with completely different modes of operation - are well-designed and widely used. The technical aspects of the purely intermittent Delou and the purely continuous Persian Wheel, together with some intermediary forms of water-raising facilities, are described in detail in Chapter 7. At this point, it is deemed sufficient to point out the fundamental differences in the two approaches to the organization of work and working time.

All work and no play? In the case of the Delou (the name derives from an Arabic

word for "water bag"), the raising sequence - lifting, emptying, lowering and filling of the buckets - is in harmony with the rhythmic motion of the draft animal: pulling (away from the well on a straight path), turn/rest, returning without load (to the starting point), turn/rest. Together, the bag, rope and water often weigh more than 60 kg, so that the drover has to pull together with the animal at certain points of the raising process. For both the man and the animal, then, there is a rhythmic succession of great exertion and relative ease.

The Persian wheel, the forerunner of the sweep power, has a completely different mode of operation. The animal trots steadily along on a circular track, thereby transmitting its energy to an endless bucket ladder (potgarland) via an angular gear. The various steps of the cycle intermingle: filling, raising and emptying of the buckets and the pulling and turning efforts of the animal all overlap. Neither of the two systems can claim superiority in principle. Both have their advantages and disadvantages. The Delou involves a certain amount of idle time, and the Persian wheel - like all sweep powers - wastes a certain amount of energy. The Persian wheel is also characterized a relatively high initial outlay and maintenance costs, though even children can operate it. The Delou is less complicated and cheaper, but its operation requires an adult with whom the animal is familiar and whose guidance it will accept. The only meaningful difference, though, lies in the attainable drawing depth, which is greater with the Delou.

No thorough, comparative analysis of the two systems has as yet been conducted, but would certainly be worthwhile. In any case, the reason for the emergence of two such dissimilar methods of raising water was a "non-technical" one: the Persian wheel was developed in Egypt or Mesopotamia, that is, in areas where life has always been decisively influenced by the eternal flow of large rivers. Most likely, bucket wheels driven by those rivers served as early models for the development of

the Persian wheel.

With the sudden rise in the use of water power during the High Middle Ages, a great many new machines, all utilizing rotary motion as the most universal driving force. also appeared in Europe. Where water power was not available, sweep powers had to fill the gap as the most obvious technical solution.

The concept of perfect rotary motion determined the development of animal-power technology in Europe. At a very early stage, efforts were undertaken to relieve the animal power of its, well, "barnyard aroma" and to at least minimize, if not entirely eliminate, the disruptive effect of the natural, unpredictable, drive-side factors on the power take-off side.

Especially with regard to nonagricultural applications, that motive soon came to be a decisive factor in most new and improved systems such as water-raising facilities in castles and fortresses, where more and more treadwheels and treading disks had come into use since the 17th century. Finally, with great structural intricacy, the aim of becoming independent from the will and moods of the animal and simultaneously minimizing the output fluctuations was accomplished by tying the animal in place - often enough with a noose around its neck - in a treadwheel or on a disk. By permanently pulling the ground out from under the animal's feet, so to speak, the animal was automatically forced to deliver the power required on the output side. The conventional animal power is an appendage to the animal, as it were; in the case of treadwheels and disks, the opposite is true.

This eliminated the necessity of someone who was familiar with the animal being in constant attendance, which certainly provided a major incentive for the use of treadwheels and disks. Moreover, fascination with the engineering feat embodied in

such ponderous new machines doubtlessly contributed to their rapid rise in popularity. (An ox-powered treading disk that was used well into the third decade of this century at Schillingsfurst Castle in Franconia is still on display there.) Without having conducted a thorough study of pertinent literature, and in the absence of practical test results, it would be difficult to say to which extent treadwheels and disks were able to effect a real increase in efficiency. Judging by the data on a water-raising treadwheel that was in operation until the mid-'30s at Conradsburg in the Harz Mountains, one could easily come to the opposite conclusion, since the system was veritably ridden with friction losses: the bearing had to support not only the weight of the disk or wheel, but also that of the animal.

With the onset of industrialization, initial improvements to the handmade wooden structures were introduced in the form of metal friction bearings and cast-iron bevel gears, which had a positive impact on the overall efficiency and reliability of animal powers.

From about 1870 on, the focus of interest shifted to other aspects, including safety of operation. Above all in the field of agriculture, the animal power was regarded as a rather dangerous instrument, though that was at least partially attributable to the frequent practice of having them operated and attended by children.

Safety problems also gave rise, at least in part, to the development of automatic coupling and braking mechanisms, for which 15 patent applications were submitted in Germany alone between 1870 and 1910. During that same period, 10 patents were issued for strain equalizers (for the simultaneous use of several draft animals) and for spring mountings.

While such modifications tended to further enhance the animal's "comfort" (and,

hence, to improve its performance), they usually entailed high costs in time and effort for their design and construction.

Also around 1870, the tread power appeared as the industrial form of the old treadwheel and disk. In addition to the advantages already discussed in connection with the latter, the new tread powers also featured a much more modest space requirement.

Nonetheless, tread powers were widely criticized because of their high price and frequent breakdowns, and because the animals often fell down or were otherwise injured in them.

Above all else, though, nature took revenge for being forced into the role of a mere appendage to the machine: the draft animals were often overworked to the point of complete exhaustion and at least temporary uselessness.

By comparison, the two automatic ("self-acting") whipping machines patented in 1886 and 1895 for use in sweep powers appear ludricrous and harmless.

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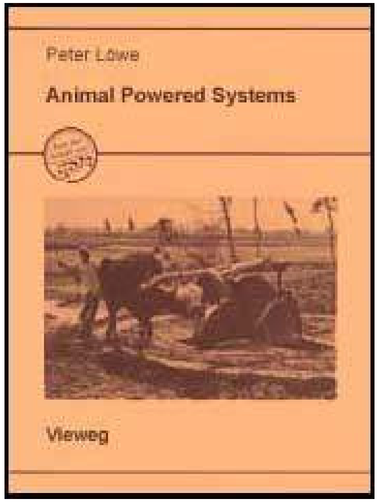


6. Water-Raising Facilities as Examples for the Efficiency of Animal-Powered Systems

Thanks to a comparative abundance of available information and, above all, to the ease with which their product can be described, water-raising facilities make good subjects for a model description of animal-power efficiency. Both the drawing depth and the delivery volume can be measured with very simple instruments. By comparison, the output ratings of, for instance, oil or grain mills, cannot be limited to quantitative data, but always require a detailed supplementary characterization of both the raw material and the finished product.

The area that can be irrigated with a certain quantity of water is dependent on so many climatic, biological and technical parameters that it would be impossible to characterize a water-raising device in terms of "irrigable area". Thus, a better way of comparing output data would be on the basis of their relative efficiency, i.e. the respective product of drawing depth multiplied by the volume of water that can be raised in a specific period of time. Such ratings can be expressed in terms of "Water Watts" (WW), calculated with the aid of the following equation: Pn (in WW) = 2.7 x

water volume (in m3 /h) x drawing depth (in m) In all technical systems, the power input exceeds the useful effect. The useful effect/ power input ratio is referred to as the efficiency of the system and is stated as a percentage. The losses may well exceed the useful effect, in which case the efficiency will amount to less than 50%.

In the case of a draw well, for example, the combined weight of the rope and bucket can easily amount to about the same weight as that of the water raised in a single cycle. In other words, each raising of the bucket involves so much non-productive work that it could even exceed the amount of productive work that is accomplished each time. Such losses can be eliminated by running the rope over a simple pulley mounted on a frame over the mouth of the well and by attaching one bucket each to the two ends of the rope. The weights of the buckets and rope cancel each other out, and the water volume raised with the same amount of work is nearly doubled.

By analogy, the capacity of animal-powered water-raising devices can often be drastically increased without raising the power input (e.g. through better harnessing, adjusting the discharge height of bucket wheels, reducing the friction losses in bearings and gearings.

Accordingly, a complete assessment of a water-raising facility should always include an evaluation of its efficiency, in addition to the indication of drawing depth and volume, i.e. of its useful capacity. That, however, is hardly possible, since it is very difficult to gauge the energy expended by the animal.

The fact that the capacity is indicated in a "technical" form, i.e. in WW, should not lead one to forget that the energy sources for traditional water-raising facilities are living, breathing beings - and thus incalculable. As shown in the examples p. 29 (Schioler, 1981), field data always require detailed interpretation.

The diagram p. 30 surveys the capacity ranges of various types of water-raising facilities driven by animals. The delivery volumes are shown as a function of the respective drawing depth (depth of well). By way of comparison, several types of manually operated water-raising devices are included. The diagram is based on actual cases of practical implementation or observation as described in the literature. The fields of application for individual water-raising facilities are not sharply defined and should not be taken as definite boundaries.

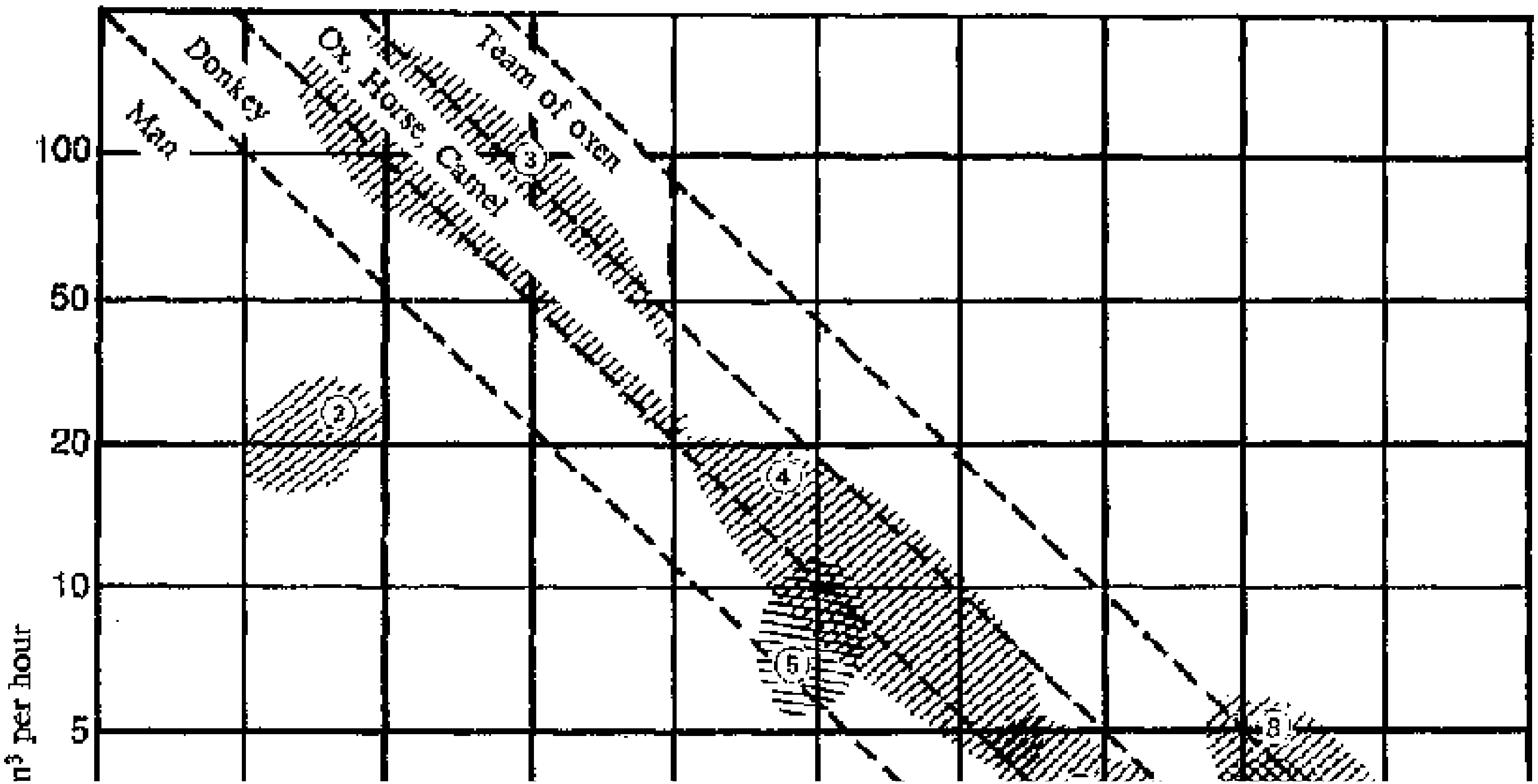
Sample capacity ratings for various types of Persian wheels (in water watts = WW).

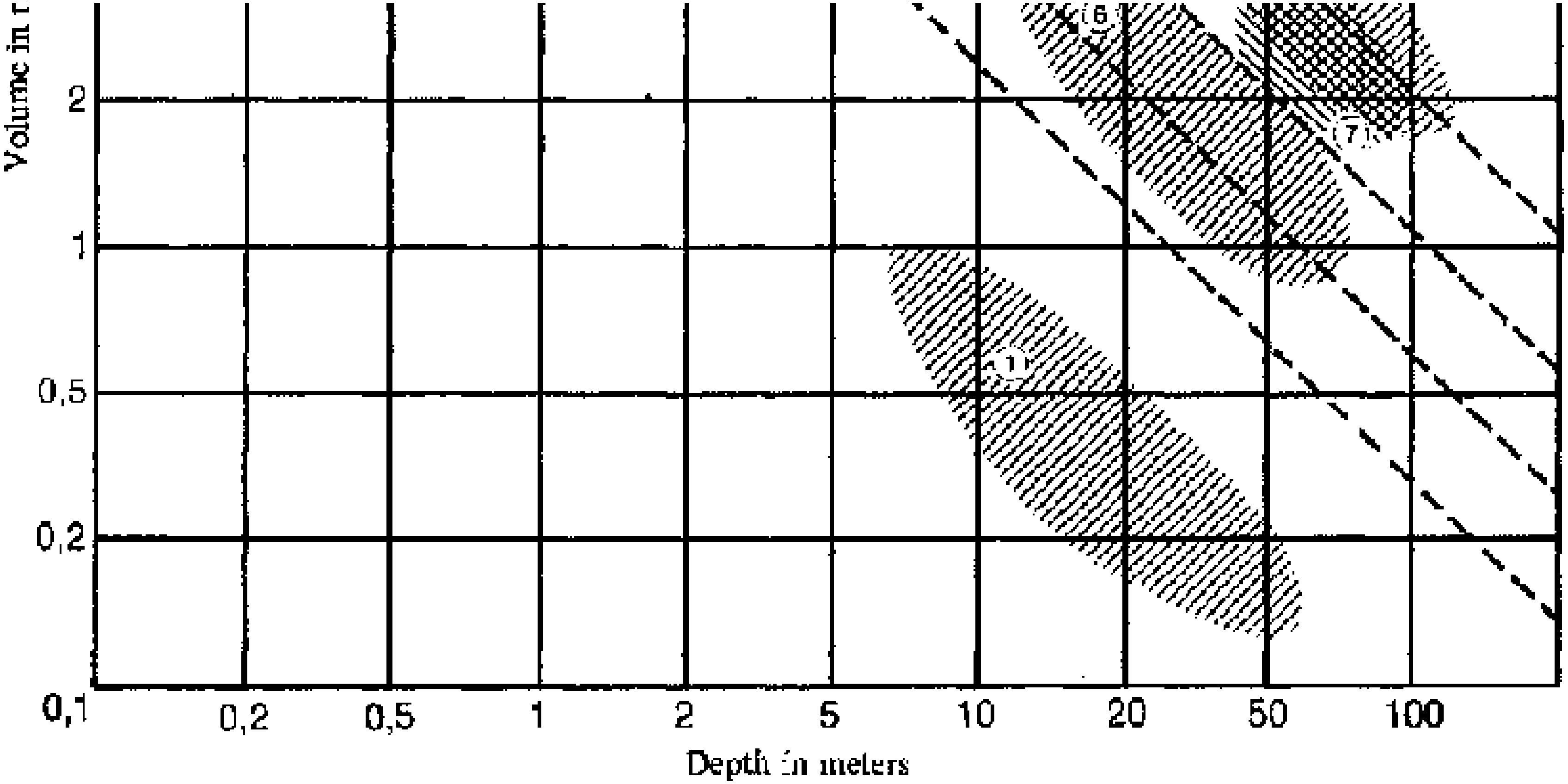
Capacity of a Spanish version (Noria de Sangre) drawn by an unattended, exhausted donkey (measured in 1955):	44 WW
Capacity of a Persian wheel drawn by a healthy, unattended bullock (measured in 1979):	90 WW
Capacity of a Persian wheel in Pakistan drawn by two exhausted oxen attended by the farmer:	170 WW
For a short time after the farmer "urged the animals on" (by whipping), the same Persian wheel delivered:	500 WW
Capacity of a Persian wheel in India:	180 WW
Capacity of a Persian wheel near Agra, India, drawn by a rested camel:	240 WW
Capacity of a well-lubricated Persian wheel in India, drawn by an ox held at top speed by an old woman with a whip (measured in 1979):	120 WW

The following capacity ranges are defined in the diagram:

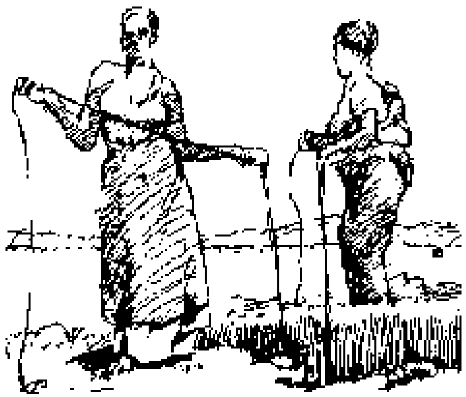
2 - 25 WW Human power
50 - 100 WW Donkeys
100 - 200 WW Oxen, horses, camels
200-400 WW Spanrigs or commercial-type animal-powered water-raising devices

As indicated, the capacity of animal-powered water-raising facilities lies between that of manually operated devices and that of motor-driven pumps. As an example, for a given irrigation perimeter, a "Gueroult" driven by a team of oxen can provide the same useful effect as the work of 10 to 15 people.

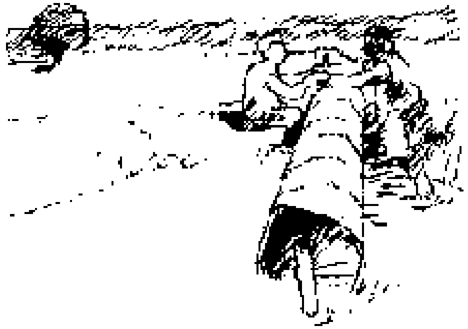




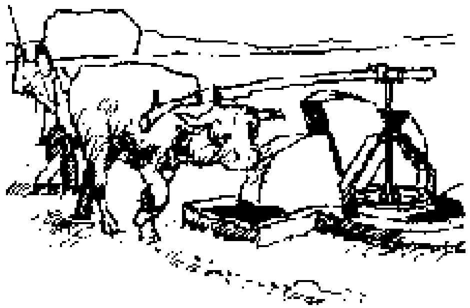
Figure



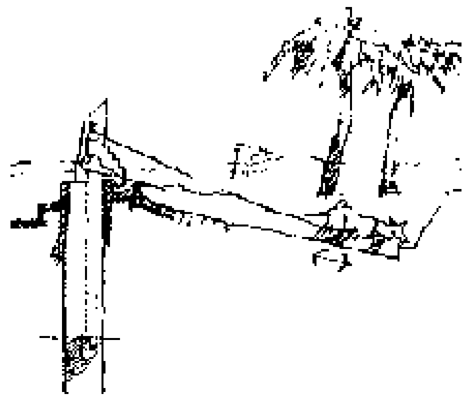
1 Traditional well



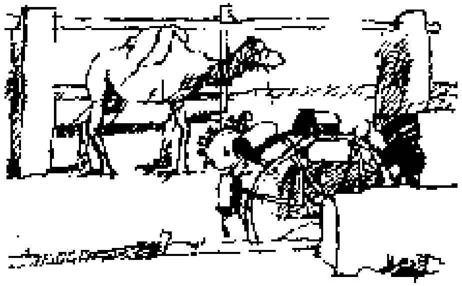
2 Archimedian screw



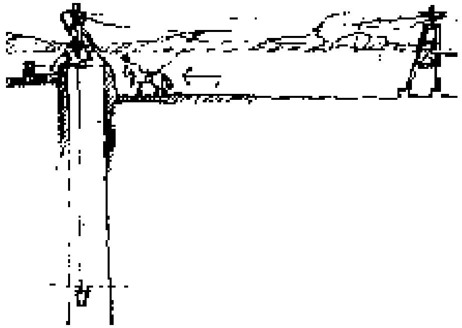
3 Spiral wheel



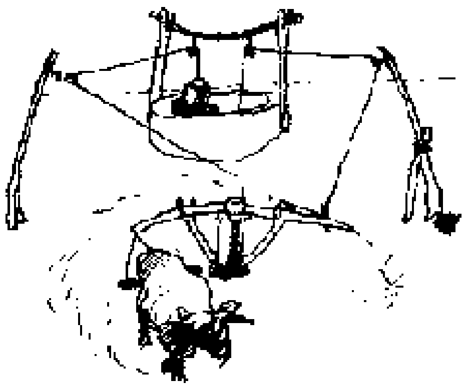
4 Noria



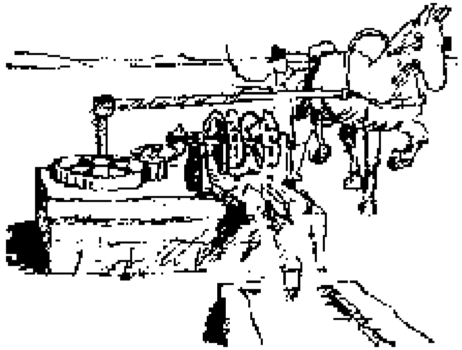
5 Stoney's Mote



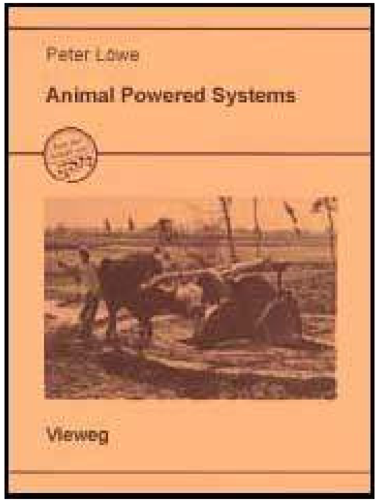
6 Delou



7 Gueroult



8 Industrial gear pump



Animal Powered Systems (GTZ, 1986, 60 p.)

7. Profiles

7.1 Water-Raising Mechanisms

The "Delou".

By tradition, Delous are used in Northern Africa' the Sahel, the Near East, Persia and India (where they are referred to as "motes". The basic components of a Delou are a water vessel, a hoisting rope and a guide for the rope.

In its simplest form, the Delou is used by nomads in the Sahel region. A simple leather bag or tube from a truck tire (cut open and sealed off on one end) serves as the water vessel. The rope guide consists of a tree limb mounted at the rim of the well. The rope pulled by the draft animal (ox, horse or camel) slides back and forth over the limb. The friction between the rope and the limb (intensified by sand) wastes part of the animal's energy and soon abrades the rope. Often enough, the rope snaps, and the bag drops into the well. Retrieving the bag is a risky operation, since the sides of traditional wells are not secured.

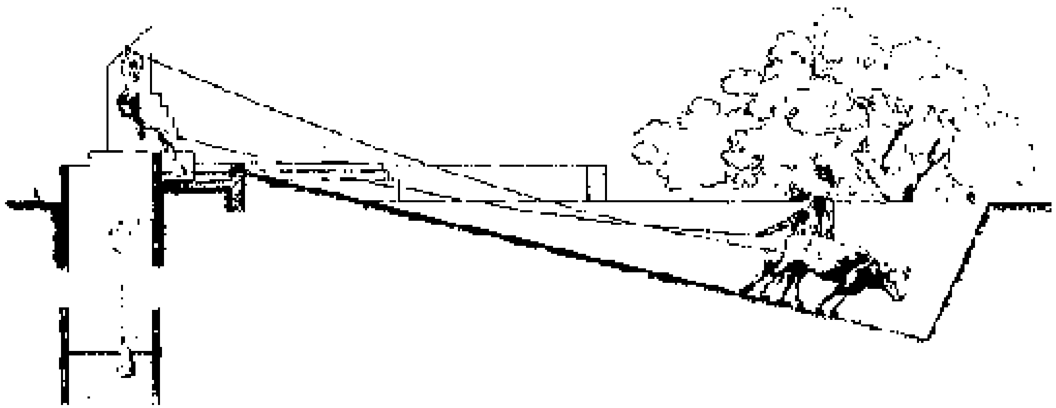


Fig.: Delou with an automatic emptying arrangement

Even a simple pulley can be of great help in improving the efficiency to a remarkable extent.

It can be made of wood in the traditional fashion or from metal. Since most nomads carry their own pulleys with them, they have to be portable, i.e. not too bulky or heavy.

Permanently installed pulleys have not proved very successful, especially when rollertype devices are used. They are often used for carrying out several drawing operations at the same time. As shown in, the pulleys are literally sawn to pieces by the sandy rope within a few months and are then replaced by the traditional limbs.

Technically superior versions of the Delou were able to develop in areas where they are used for purposes of irrigation by sedentary populations (Northern Africa, Persia, India). Apart from a stationary framework with sturdy pulleys, such Delous feature means for automatic emptying of the water bag and a more efficient utilization of the applied tractive power. The framework consists of either a simple structure of wooden beams, brickwork, or a combination of the two. It is often equipped with pulleys for two simultaneous but. independent water-raising operations and is accordingly robust.

For the purposes of automatic emptying, the bottom end of the water bag has a tubular extension with a rope attached at the end. The other end of the rope (like the pulling rope) is fastened to the yoke of the draft animal. The drover keeps it taut during the raising process, so that the tube buckles over and seals off the water bag. When the bag arrives at the mouth of the well, the drover pulls on the rope so that the water runs out into the channel at the well's rim and flows into the irrigation ditch or watering trough.

The most laborious improvement over the nomadic version of the Delou is the construction of an inclined plane for the animal's pulling path in order to more

uniformly distribute the draft animal's strength over the full work cycle: Part of the energy accumulated by the animal by climbing up the slope can then be used to its own advantage on the way back down. It has not yet been determined to just what extent the considerable variance in the angle of the slope (10° - 30°) is attributable to less-than-optimum planning or just the opposite, namely quite specific optimizing, e.g. in deference to different breeds of draft animals.

At any rate, rhythmic motion is maintained. Also, at the lower end of the inclined plane (that is, upon completion of the pulling phase), the animal is allowed to rest for a little while.

Occasionally, feeding troughs are provided there.

The "Guroult".

An advanced version of the Delou - also aimed at improving tractive-power utilization by avoiding energy wastage on the draft animal's way back to the well, is the so-called "Guroult".

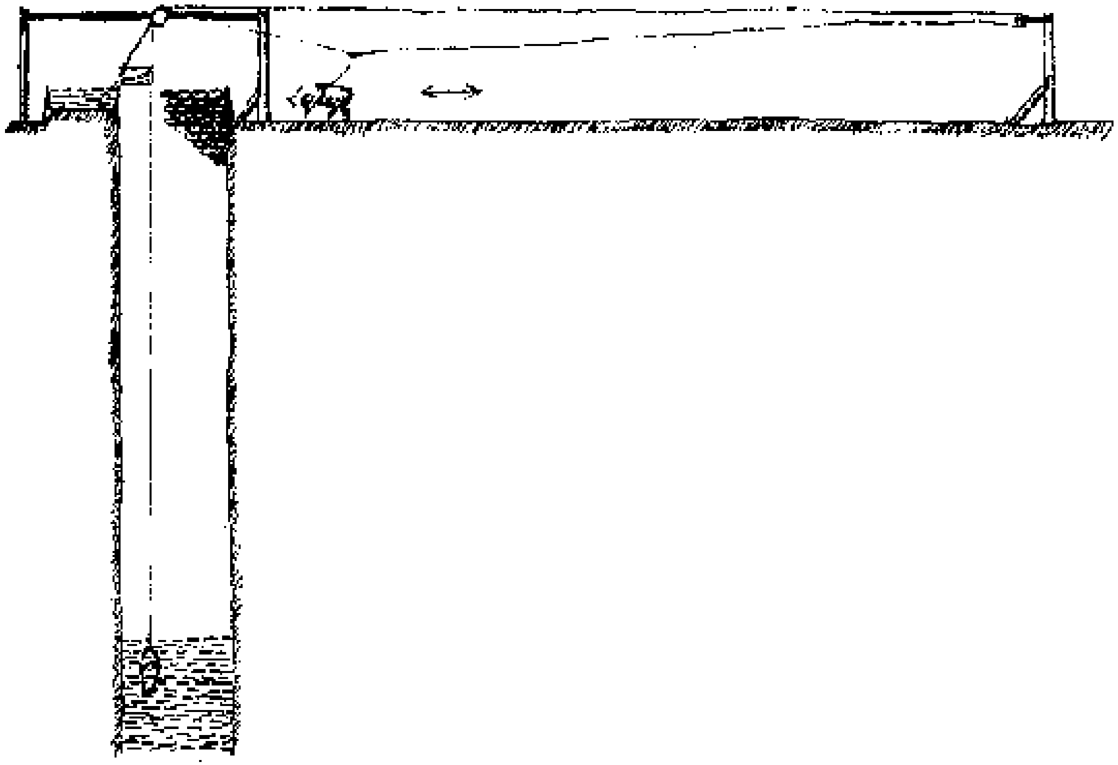


Fig.: Guroult

Originally developed by the "Institut Sngalais de la Recherche Agronomique", about ten such systems have been installed in Senegal since the early seventies by Pre Lebegue of "Mission Catholique de Gossas", the Senegalese Appropriate Technology Group ENDA, and the "Institut Technologique Dello".

The Guroult has two buckets with a volume of about 501 each that are alternately filled and emptied. They are fastened to the ends of a steel cable with a full length amounting to some 3 1/2 times the depth of the well. The cable is guided by two pulleys over the mouth of the well and a third pulley mounted on a framework at a distance from the well that roughly corresponds to the well depth. The team of oxen

(Guroults are usually operated as spanrigs) is harnessed to the middle of the cable, so that one raising phase each is carried out on their way back and forth.

An important advantage of the Guroult as compared to the Delou is that the 'cable (or rope) never drags along the ground, which prevents pollution of the well. This is thanks to the heavy weight of the iron water buckets (40 kg), which keeps the cable taut. On the other hand, the heavy buckets also constitute one of the disadvantages of the Guroult, namely the extensive wear and tear to which the wall of the well is subjected through their constant bumping.

That problem has been greatly alleviated by an improvement introduced by Pre Lebegue (a foot valve). In addition, recent developmental progress at the "Institut Technologique Dello" has contributed much to reducing the cost of installation and maintenance. Nonetheless, since the entire construction is made of steel, the cost of a Guroult still exceeds the financial means of the average Senegalese farmer.

Recent investigations also indicate that women can expect to reap little of the advantages of a Guroult: Since women have no say over the family's draft oxen, the mere existence of a Guroult on the farm may tend to increase a woman's dependence on her well-to-do husband (who owns the oxen).

The "Mange du Jardinier".

The Mange du Jardinier also has two delivery vessels for alternate raising and lowering.

Each bucket is tied to the end of a rope, and each rope runs over its own pulley at the mouth of the well. and continues on to a third, common pulley (a vertical drum),

where one of them is wound up while the other is payed out. As in the case of a continuous system, the draft animal moves along a circular track, but has to be turned or reharnessed after every raising of a bucket (as is the case in an intermittent system) in order to backtrack along the same circular path.

Since the drum and the circle described by the animal are of different diameters the Mange du Jardinier also constitutes a simple gear unit. Depending on the ratio between the two diameters, the tractive power is in creased and the speed decreased by a certain amount.

This system is especially suitable for lifting heavy loads. While illustrates as well-building application' the system is equally suitable for water-raising purposes, in which case relatively large delivery vessels are required. For a drum diameter of 1 m, a circular track diameter of 6 m, and tractive power of 30 kp, the vessel volume would have to be approx. 160 l (with due account for the weight of the rope). Accordingly, the framework, pulleys and ropes must all be sturdier than for a Delou or Guroult. On the other hand, the time lost during reharnessing or turning is less signifi cant, because the raising cycle for each bucket is longer. The system does not require much space, and one person is usually sufficient for its operation.

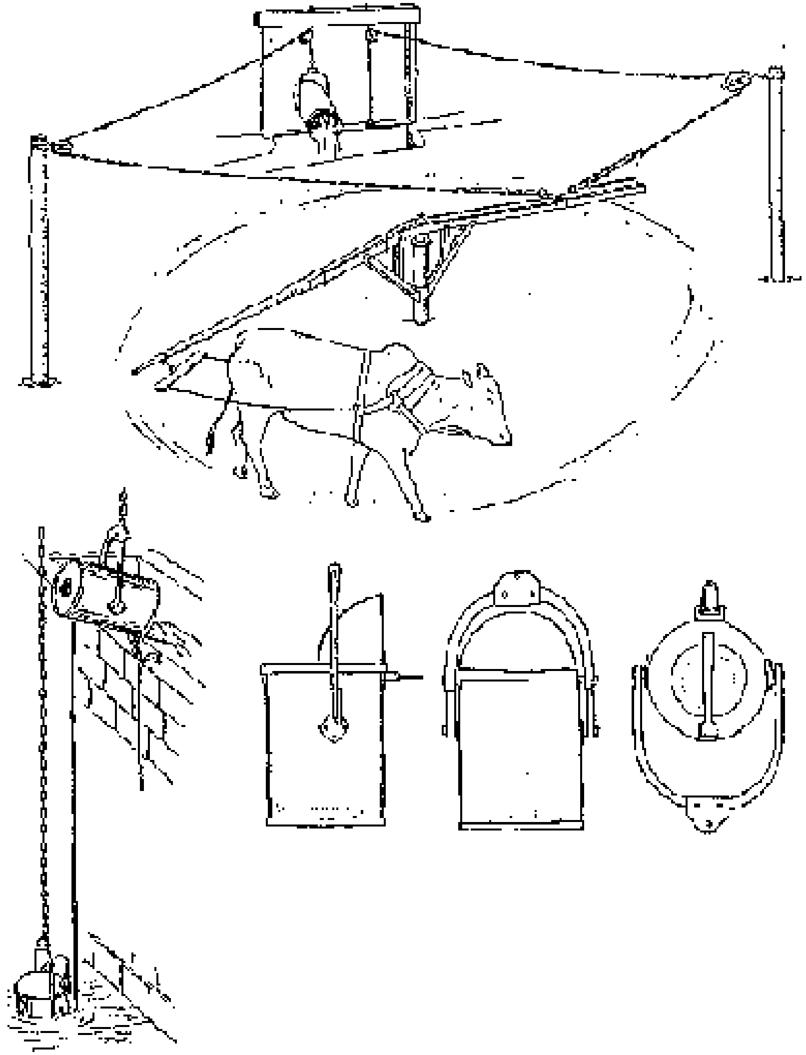


Fig.: Mange du Jardinier - once used for well building

The Mange du Jardinier is well suited for low tractive power and relatively large depths. For example, pertinent literature contains a reference to such a system in a fortress in Palestine where water was raised from a 55 m deep well by a donkey, whereby a special device enabled automatic emptying of the bucket, and the donkey is said to have reversed direction on his own whenever it heard the sound of the

bucket being emptied.

Stoney's Mote.

This water-raising arrangement was designed by British colonial engineers just after the turn of the century. It is also frequently referred to as "Mote de Ceylan" (after the region in which it has become most popular). And since it combines the intermittent raising and emptying of buckets with the continuous circular motion of draft animals, it is sometimes called a "circular mote".

Stoney's mote is a simple, practical application of one of the basic elements of engineering: the crank. Cranks are used in engineering wherever rotational motion has to be converted to linear back-and forth motion (or vice-versa), be it in a bicycle, an internalcombustion engine, or whatever. In the case at hand, the circular motion of a draft animal is converted into the rhythmic alternate raising and lowering of two delivery vessels by attaching the center of the pulling rope or cable to an off-canter point on the drawbar and running the two half lengths to the buckets via two pulleys each - one each over the mouth of the well, and one each on (either) side of the circular path.

Figure below illustrates the basic principle of function and automatic filling and emptying of the buckets. The drawing depth of such a simple circular mote is equal to twice the distance between the pivotal point of the drawbar and the point at which the pulling rope is attached to the drawbar, and is thus limited to 5-8 meters. As long as the buckets are emptied automatically - and rapidly enough - the animal needs not stop at that point, but should at least slow down somewhat, since the geometry of the arrangement is such that the buckets move slowly in the vicinity of their reversing points, i.e. for filling and emptying. They move most rapidly about one-

third of the way through the raising/lowering phase.

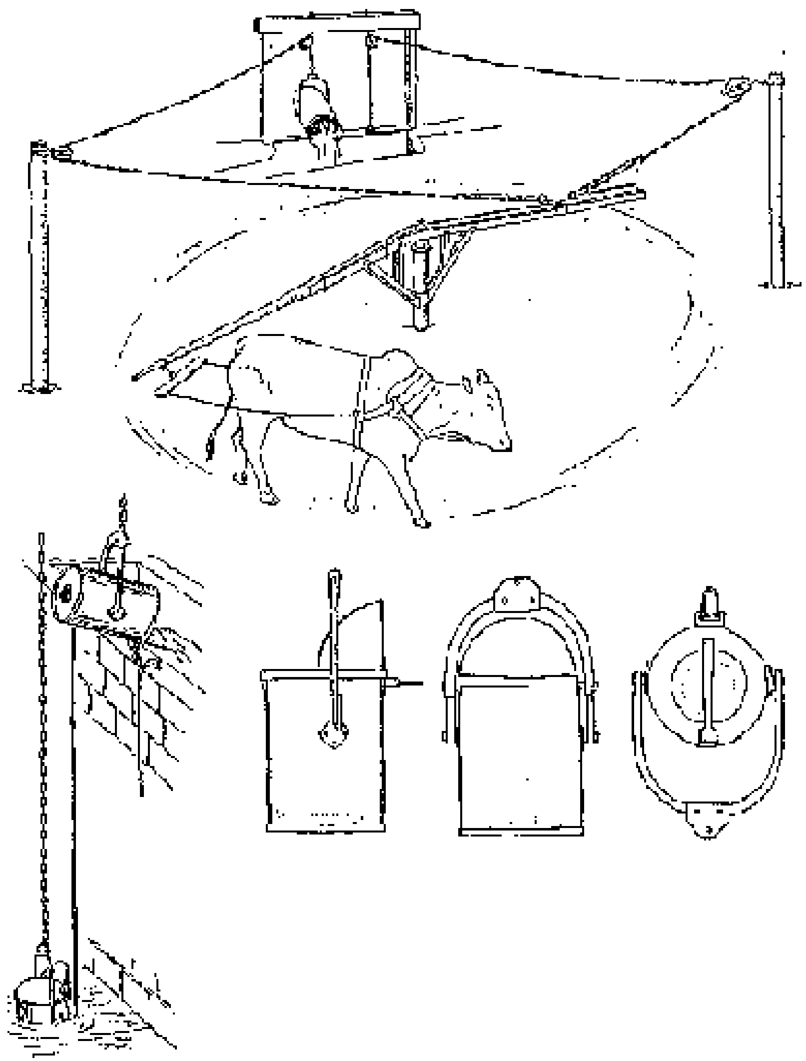


Fig. 32: Stoney's Mote, basic concept

In each such instance, i.e. when the cable is tangent to the circle defined by its point of attachment, the animal has to deliver the most tractive power. In other words, due to the intermittent delivery, the required tractive effort varies from moment to

moment. It increases from 0 to maximum during the first third of each drawing phase and then gradually drops off to 0 again at the end of the phase. Thus, as the animal traverses: a full circle, the requisite pull swings twice from 0 to 100%. The maximum pull depends on the geometry of the drawbar structure and can amount to any value, between 50 and 100% of the weight of a full bucket.

Due to the varying tractive power in combination with the unidirectional, circular path described by the draft animal, Stoney's mote may be regarded as a cross between an intermittent and a continuous water-raising device.

In the elaborate version of Stoney's mote in Sri Lankam, the drawbar is equipped with a supporting wheel and a seat for the drover. A block and tackle arrangement is used to quadruple the drawing depth. The prototype of a simplified circular mote has recently been developed by the "Institut Technologique Dello" in cooperation with GATE. It is made almost entirely of wood, and the chains have been replaced by nylon ropes. Conceivable measures aimed at smoothing out the tractive power curve (more buckets, counterweights, etc.) have not yet been tested in the field. Presupposing a satisfactory arrangement for automatic emptying of the buckets, Stoney's mote could well be one of the most attractive solutions for drawing depths of about 6 m.

The "Mange Sahores".

The Mange Sahores is a modernized version of the circular mote for large drawing depths.

The buckets have been replaced by a pump and a counterweight (figure).

This water-raising rig was designed by the French engineer Jean Sahores, who since the mid '70s has been working on simple wind-driven, hand-operated pumps, primarily for use in the Sahel. The overriding principle behind all of his developments is that the appliances can be built and maintained by local craftsmen. In the case of the pumps, this is achieved by using plastic pipes that can even be cut and processed by the farmers themselves.

The Mange Sahores employs such a pump. The maximum achievable pumping depth is presently about 15 meters, though 25 m would appear feasible.

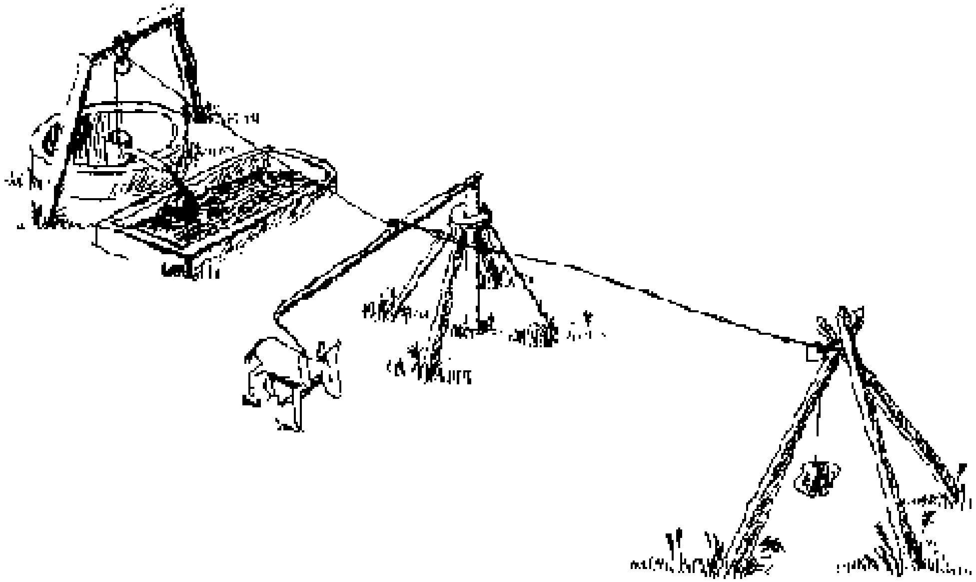


Fig.: Mange Sahores

Mange-Sahores systems are presently under" going field testing by Jean Sahores himself the "Institut Technologique Dello" and at several locations in Senegal.

In a GTZ project in Southern Senegal, a pro" totype Mange Sahores with a drawing depth of about 10 m has already achieved delivery volumes on the order of 2.3 m3/h.

The donkey providing the power for system operation puts in a 4-6 hour workday.

Waterwheels.

Waterwheels, in all their many variations, are regarded as classic examples of Arabian/Islamic culture as applied to the task of raising water. Invented in ancient times, preserved and sophisticated in Arabia, rediscovered first in Southern Europe and then in Central Europe, waterwheels are typical representatives of a polyglot, international technology.

"Fetching up the waters" was a major discipline in the classic natural sciences of Arabia.

Numerous, voluminous reference works offer quite practical instructions on how to locate groundwater, how to judge the quality of well water, etc., as well as a host of more esoteric reflections, such as the hope accompanying the many deliberations on how to improve waterwheels to the point of perfection, namely to turn them into "per petua mobilia".

Thus, in Arabian-Islamic culture, waterwheels are far more than mere technical objects.

They are so deeply rooted there that they have given rise to a literary genre all of their own - "waterwheel poetry" - in which the creaking and groaning of the wooden wheels is besting and from which they have derived such poetic names as Noria ("the wailing one") and Hanana ("the moaning one"). Even a sober-minded French colonial engineer was so caught up by their magic at the turn of the century that the report he filed included the poetic remark: "The Saqia announces its presence from

afar; its incessant moaning and plaintive groaning pierce the quietude of the plain, trouble the peace of the night, and underline the cost and effort that man must pay for bringing fertility to the arid soil." The quality of a waterwheel, then, may be judged as much by the sound it makes as by its efficiency. Similar irrational factors surely play, or have played? a like role in numerous other innovative processes. Aware of that fact, many industrialists enlist the aid of psychologists and designers. Unfortunately and all-too-frequently, scholars of "Appropriate Technologies" tend to rely on a line of argumentation that only stresses technical efficiency and cost effectiveness.

Waterwheels can be classified either by their actual mode of operation and achievable drawing depth or by the type of power transmission they employ, whereby the latter serves in redirecting the animal's rotary motion (horizontal plane) onto the waterwheel (vertical plane).

A wide variety of wooden angular gears are used, e.g. two star wheels of approximately equal size in Egypt, or a horizontal lantern wheel in combination with a vertical cog wheel in Spain and Morocco.

The greatest drawing depths can be achieved with potgarlands ("Noria": 5-20 m, figure below), followed by bucket wheels with the water vessels arranged around or integrated into the wheel perimeter ("Tabout": 2-4 m, figure below) and spiral wheels ("Tympan": 0.3 - 2.5 m, figure below).

With but a single exception, all waterwheels have the same disadvantage: they "overlift" the water, i.e. they raise the water to a higher level than necessary. This is particularly wasteful (with regard to energy input) when the difference between the discharge height and the outflow level is of the same magnitude as the drawing

depth, i.e. for shallow drawing depths.

Spiral wheels are the only version with which overlift can be avoided, since that is the only design that raises the water inside of the wheel radius (like an Archimedes' screw) and discharges it through the wheel axis. First figure - taken from Jakob Leupolt's "Muhlenbuch" (published in 1728) - includes two examples of the spiral-wheel principle (nos. 10 and 11).

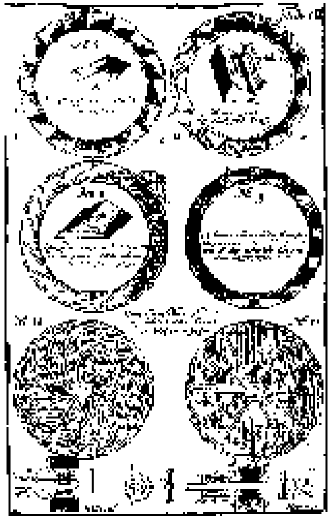


Fig.: Water lifting wheels, from Leupolts "The book of mills" (1728)

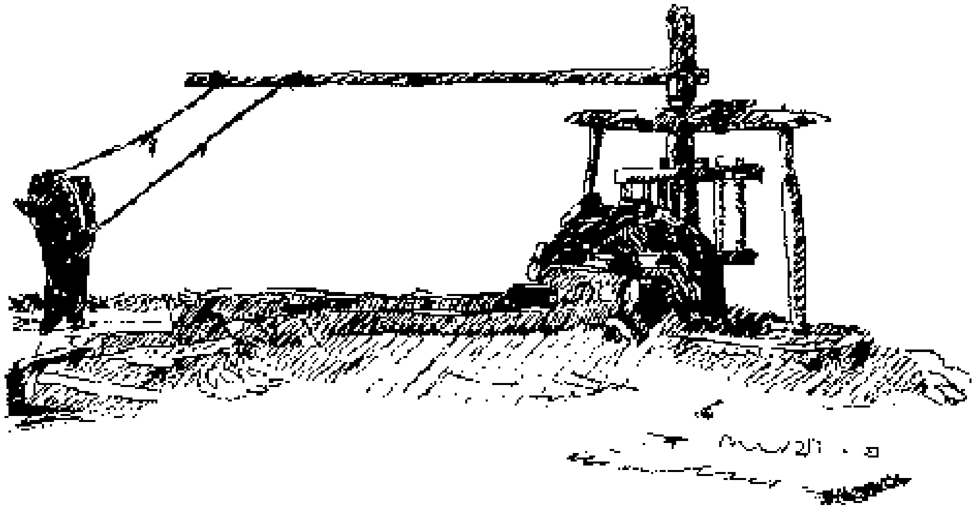


Fig.: Noria (bucket wheel), drawing depth: 5-20 m, "Senia"-type (Morocco)

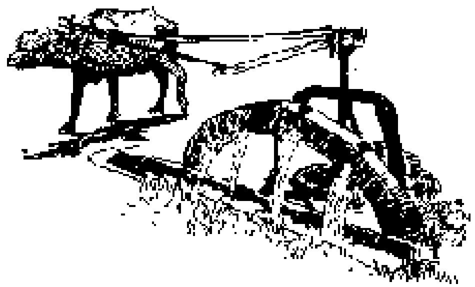


Fig.: Tabout, drawing depth: 2-4 m (Egypt)

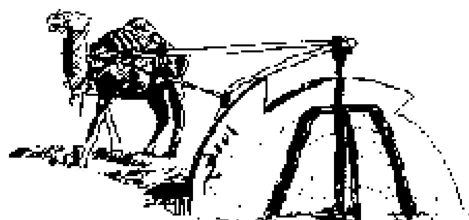


Fig.: Spiral wheel, drawing depth: 0.3-2.5 m (Egypt)

The most significant practical example of a "Noria" is the "Moorish Noria" which, in its original all-wood form, can still be found in Morocco, where it is called the

"Sepia". An improved version with certain components made of metal is still in use on the Iberian Peninsula and on Spain's Mediterranean islands.

The Senias of Beni Boufrah valley in Northern Morocco have drawing depths of between 10 m and 16 m and are capable of irrigating vegetable gardens ranging in size from 1000 m2 to 5000 m2 They are operated almost exclusively by donkeypower, with the donkeys working up to 8 hours per day. Built by the farmers themselves, the Senias have such high friction losses that their efficiency is extremely low (roughly 255%. The improved Spanish version, however, seems to achieve up to 50% efficiency.

With a total number of some 400000 waterwheels (Saqias), Egypt is still one of the classic waterwheel regions. Saqias, though, are rarely used for watering small vegetable patches, but primarily for irrigating large fields of grain. On the average, a single saqia is used for about 6 hectares (~15 acres). This is made possible by the high ground water level (0.3 - 2.0 m), together with more powerful draft animals (cattle) and more efficient designs (usually a spiral wheel and cast-iron bevel gears). While some wooden gears and less-efficient types of waterwheels (Tabout or Zawafa) are still to be found, Egypt is still a shining example of the fact that - given the appropriate political environment - a highly developed handicraft trade will usually be capable of creatively sophisticating its own traditional techniques through the introduction of new materials.

Animal-Powered Industrial Pumps

Around the turn of the century, dozens of European and American firms made or marketed industrially manufactured, animalpowered pumps. In most cases, universal power gears were combined with pumps of different maces of operation. Depending

on the requisite drawing depth, the pump would be of the piston, diaphragm, rag or centrifugal type.

Their market niche, apart from the colonies of that period, mainly comprised small to medium-sized farms in metropolitan areas. In rural France, for example, some such pumps remained in use until the 1940s.

Like most other machines of the time, animal-powered pumps were very heavy, sturdy appliances. While importance was attached to durability and ease of maintenance, it was not intended to provide for the manufacturing of such machines in the colonies. Since no empirical data are available on the practical use of these pumps, the suppliers' old advertising brochures and catalogues are the only sources of performance data. In most cases, though, such material is full of inaccuracies and exaggerations, as well as being generally based on operation by heavy draft horses. Thus, the capacity ratings ranging from 300 to 400 WW, have to be taken with a grain of salt, even though such pumps really could work at higher efficiencies - as long as they are properly operated and maintained than would be attainable with the traditional systems described above.

The second-best sales argument (just behind the performance data) in the advertising brochures was the more-or-less "quiet" running of animal-powered pumps: But such pumps, especially the piston and diaphragm versions, required flywheels, belt drives or intermediate gears (for transmission to higher speed) to protect the animal from load fluctuations and shocks resulting from the intermittent principle of operation. In addition, the number of cylinders was often increased, so that three-cylinder animal-powered pumps were no rarity. No problems in this respect are encountered with the continuous-action rag pump, which, despite its relatively high maintenance requirement, was quite popular at that time.

Today, such animal-powered rag pumps are available from the Indian company Cossul. The delivery rating of 10 to 15 m3/h for a drawing depth of 13 m (corresponding to approx. 400 WW) seems to be somewhat overly optimistic. The current prices and supply details were not known at this printing.

A very revealing case history on the use of industrial animal-powered pumps in developing countries was filed in 1983 by Pierre Guillaud Brandon: Between 1962 and 1966, the "Service des quipements ruraux 83" in Morocco installed a large number of animalpowered pumps of a type designed and manufactured by the Gillaud Co. of Casablanca. The aim was to improve the potable water supply in remote villages. The pumps were designed for well depths of anywhere from 10 m to 77 m, i.e. depths for which the traditional Moroccan Noria could not be employed. After several trial installations, a rather complicated version with a double- action pump, a 45-kg flywheel and a progressive transmission was decided on. Though the initial cost of such a pump was as high as that of a motor-driven pump with a much higher capacity, the operating costs were so low that all cost-effectiveness analyses came to the same conclusion: the animal-powered pump was, in the long run, considerably cheaper than a motor-driven pump. Then, in 1970, a survey revealed that only 25 of the pumps had achieved an average service life of about 15 000 hours (approx. 3 500 operating hours per year). The vast majority of the pumps was out of service, mostly due to relatively minor breakdowns (broken linkage, jammed transmission, etc.), that the users did not have the means to repair.

In his review assessment, Pierre Guillaud Brandon came to the conclusion that the anticipated maintainability was unachievable in spite of all the engineering effort that had been put into the design. The degree of reliability requisite to a safe supply of potable water could only have been warranted by a team of maintenance specialists. That, in turn, would have seriously diminished the cost advantage and been too

expensive for the users. Thus, it should come as no surprise to the reader to learn that the last pump that was still in operation in 1983 was found to be in the hands of an "entrepreneur" who sells the water he raises to the village inhabitants. This example illustrates quite clearly that the efficiency advantage offered by industrially manufactured pumps for animal-power operation can be lost very quickly due to expensive, complicated repairs.

7.2 Animal-Powered Mills

Aside from water-raising applications, the potentially most important use of animal powers is, doubtlessly, the grinding of grain. Due to the prime importance of product quality, the situation is, by comparison, much more complex. This is particularly true in view of the fact that in practically any culture, food and food processing have always represented definite domains of the irrational. Thus, it is hardly possible to categorize the quality of comparatively simple food products such as flour in a generally valid manner. Compared to scientifically quantifiable factors like nutritional value, color or keeping qualities, questions of taste, social status and religious or other fundamental convictions can play a decisive role in such matters.

The simplest type of animal-powered mill is the gearless stone mill, known in antiquity as the "hourglass mill" (figure below). The name derives from the characteristic shape of the runner (upper millstone), which rests on a perforated metal plate and a metal pin mounted atop the conical bedder (lower stone). In most cases, the runner was turned by donkey power acting on drawbars anchored in the grooves of the runner. The grain was poured into the hollow upper cone and gradually found its way through the perforated plate and into the grinding furrow due to the stone's vibrations. No information is available on the achievable quality of the product from such mills.

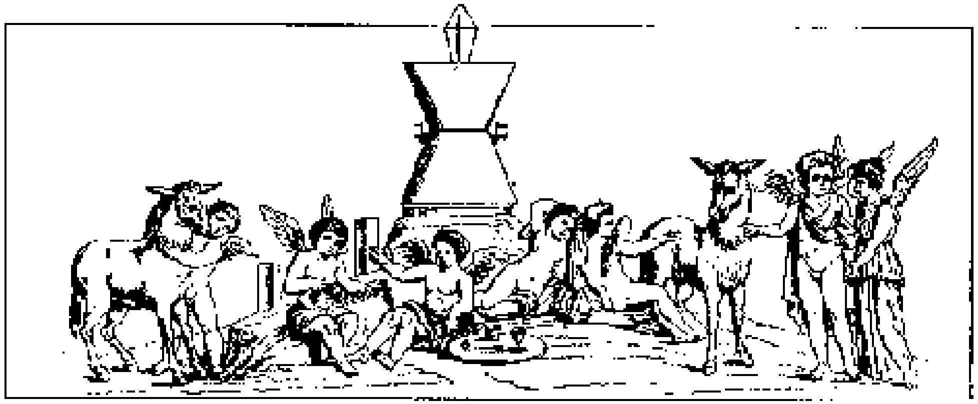


Fig.: "The miffing feast" (Vestalia), mural from Pompeji

The capacity can be enlarged by increasing the speed of the runner, e.g. by installing a pair of simple gears. Figure below depicts such a modified mill from Tunesia.

While many different types of stone are suitable for use as millstones, the best ones (but' the most difficult to cut) are made from lava. No matter what kind of stone is used, though, its grinding surface has to be "sharpened", i.e. provided with cutting edges, the shape of which is decisive for good grinding quality and smooth running.

A more modern type of animal-powered mill is the combination of a universal power gear and a commercial-type mill' whereby the latter must be of the disk type, since hammer mills operate at speeds that are too high for an animal-power drive.

As indicated above, no definite statement can be offered with regard to the throughput capacities of animal-powered mills. In approximate terms, a donkey-powered mill can probably be expected to handle 10-30 kg of flour per hour, while oxen are capable of increasing the output to something on the order of 100 kg per hour.

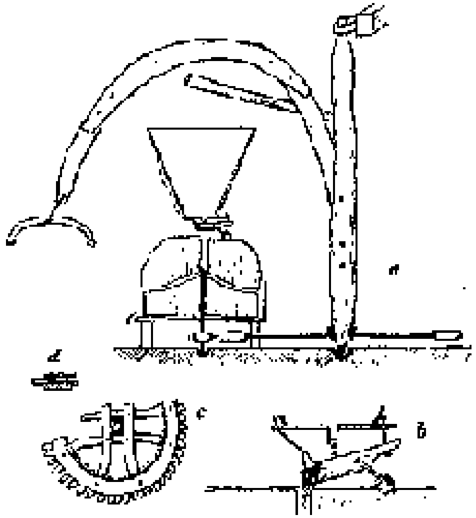


Fig.: Schematic sketch of a geared stone mill (Tunesia, approx. 1910). A) side view, b) hopper and shoe (vibrator), c) driving-end cog wheel, d) teeth mounting arrangement

7.3 Sugar Cane Crushers

Animal powers are frequently used for driving sugar cane crushers. Such units usually comprise two or three roller crushers made of wood, stone or steel. A crusher that installed by the French on a Haitian sugar cane plantation in the 18th century. The same technique is still in use on family farms in South America. Also there is a Columbian version, i.e. a "Trapiche" sugar cane crusher. Basically the same technique, but powered by oxen, is also used in India. The conventional types employ stone rollers. Beginning in the late 19th century, steel crushers were imported from England and the USA and then copied by Indian manufacturers. Beginning in 1930, the Imperial Sugar Institute (now the National Sugar Institute) in Kanpur began a series of tests and investigations that eventually led to the development of the so-called "Sultan crusher", which is still manufactured by various factories in India and Pakistan.

7.4 Universal Power Gears

With the separation of driving unit and machine, universal power gears gained wide acceptance in Europe and, somewhat later, in the USA. A wide variety of machines was developed especially for universal power drives. Some agricultural applications that are still of topical interest include: pumps, mills (for meal and flour), threshing machines, choppers, hay balers, and machines for husking and shelling corn.

Such units can be subclassified according to the type of gear of method of power transmission between the gearing and the machine.

As for the type of gear, the following essential differentiation is made:

- **spur gears**
- **trestle gears**
- **cap or security gears**

Power transmission was effected with either a cardan shaft (routed through a duct located below the circular track) or an overhead drive belt. The disadvantage of using a cardan shaft is that it requires the excavation of soil, and there is risk of breakage in the event that the machine jams up. The disadvantage of the drive belt ("Pinet" - or overhead gear) is the necessity of fortifying the main bearing against the high bending moment and of protecting the gear structure from tipping over. Moreover, the drive belt is a further source of power losses, especially in high humidity and under insufficient tension.

Relatively simple designs can be employed for stationary indoor powers, where the forces can be absorbed by fixation to the ceiling structure, and the angular gear can

be replaced by a crossed flat belt.

7.5 Sweep-Power/Runner-Wheel Combination

This last profile is devoted to the sweep-power/runner-wheel combination, which operates on an ingenious and hardly known principle of operation. Its greatest advantage is that at least part of the gearing can be dispensed with, thanks to a runner wheel that is attached to the end of the drawbar and runs along behind the animal. Its speed of rotation far exceeds that of the drawbar. The power is transmitted to the machine via shafts, gearwheels or belts and can be varied in steps by using runners of different size. In addition to increasing the speed of rotation, the runner wheel also serves as a friction clutch, i.e. as a safety device. Thus, this combination is often referred to as a "friction power".

The principle of the sweep-power/runner-wheel combination was probably first applied by the French company Tertrais et Carliers, of Chatelerault, which exhibited a power of that description at the Paris World's Fair of 1867. Incidentally, in the German literature, this principle was presented years later as an entirely new invention and attributed to at least three different inventors. In 1888, a German patent was even granted for the sweep- power/runner-wheel combination.

The experts' evaluation of the principle was contradictory. Some described it as "by no means worthy of imitation", while others expected that "within the next few years, this system will have completely supplanted all other types of geared powers in use up to now".

At least the latter prognosis has not been fulfilled. The sweep-power/runner-wheel combination has continued to lead a shadowy existence and was not incorporated

into the product lines of any big manufacturers. In part, this may have been attributable to the necessarily complicated design (with steed wheel and circular runner rail).

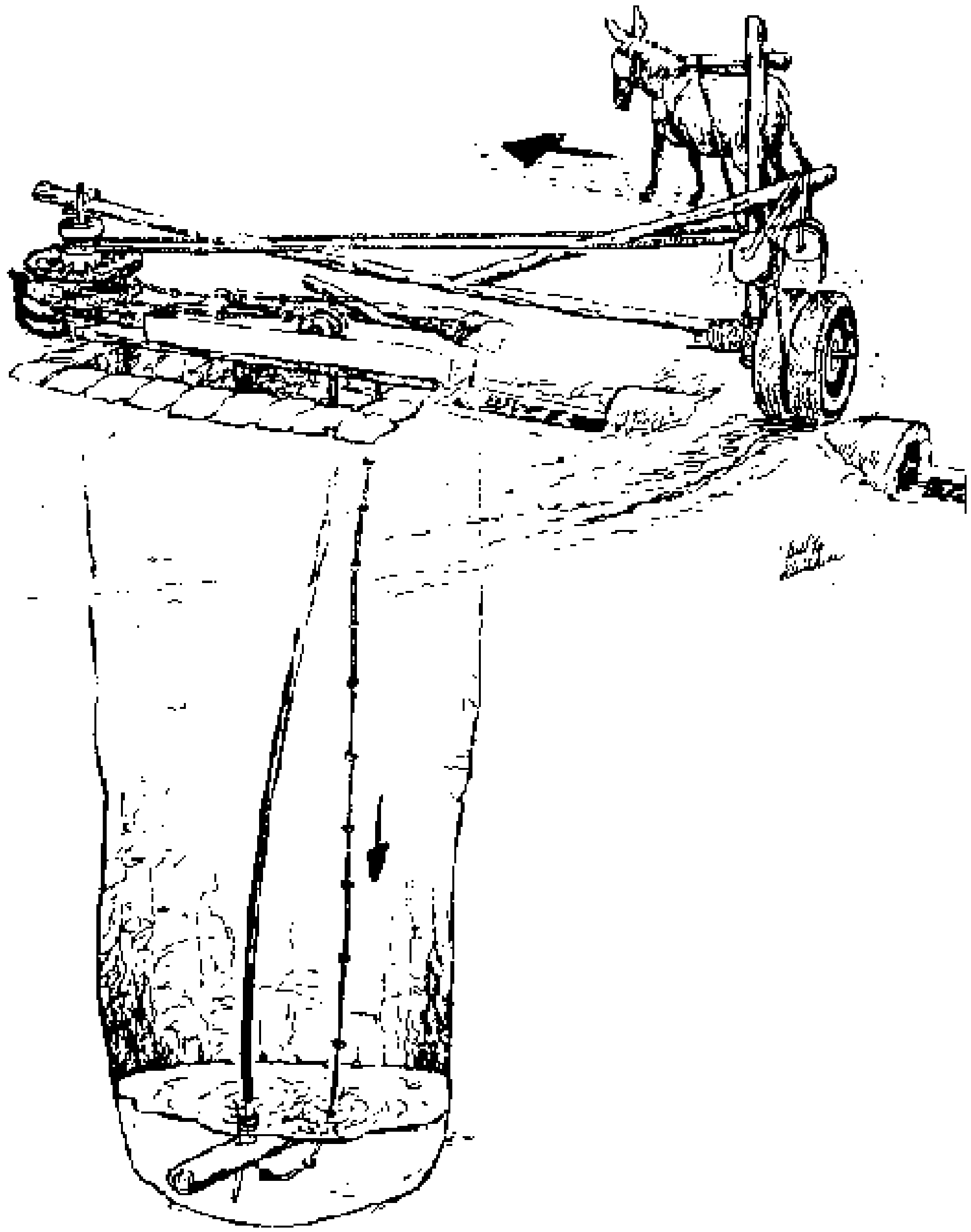


Fig.: Animal power with runner wheel in combination with a rope pump (basic concept)

The combination did not last long enough to experience the birth of the rubber tire (which was instrumental to the success of the tractor). If, however, such combination powers were to make a modern-day comeback, it would most probably be thanks to automobile tires -a mass-produced - and therefore lowpriced - industrial product in use all over the world. Accordingly, the three new constructions best-known to date and described briefly in following are based on the use of a car tire as their main component. A photo by Swiss engineer Oehler-Grimm shows an animal-powered pump in Botswana, about which, unfortunately, no further information is available. It is apparently a series product with a reciprocating pump installed at the bottom of the well and driven by the runner wheel via a crank mechanism, reversing chain and appropriate linkage. At the time this shot was taken, the pump had apparently been out of service for some time; the tire was dismounted. The outage may have been caused by accidents mentioned in Mr. Oehler-Grimm's report. Allegedly, a child was run over by the runner wheel. The extent to which such a unit could be manufactured by manual means (e.g. in combination with a "Sahores pump") should be determined by way of practical experiment. There is a Dutch proposal for a hand-made version' in combination with a rag pump (in the form of a rope pump with its rope running through a plastic sheath). At copy deadline, it was not yet known if the design in question had already been tried out in practice. Also, there is the prototype of a universal animal power developed by two students of engineering (Boie and Krause, Cologne) that works along the lines of the sweep-power/ runner-wheel combination. The design was deliberately adapted to the requirements of developing countries and includes, to the extent possible, only such components as would be locally available. Allowing for the correction of a few design deficiencies, this model should be very well suited for imitation and trial in a developing country. The photo was taken on the occasion of a demonstration organized by GATE in August of 1982.