AVDELNINGEN FÖR
VA-TEKNIK
Lunds Tekniska **Högskola**
Lunds Universitet

DEPARTMENT OF
ENVIRONMENTAL ENGINEERING
Lund Institute of Technology
University of Lund

Mr. Hofkes

COPY

PISTON SEALS FOR HANDPUMPS

DRAFT

LUND 1987

HENRIK ASPEGREN
ROBERT HAHN
PER JOHANSSON

Postadress/Postal address
Box 118
S-221 00 Lund
SWEDEN

Gatuadress/Office address
John Ericssons väg 1

Telefon/Telephone
046-10 70 00

Telex
LUNIVER
S-33533

ABSTRACT

Laboratory tests of deep well cylinder assemblies for handpumps have been carried out at the Dept. of Environmental Engineering since 1982. The tests were linked to the activities of Sholapur Well Service until 1986 when the World Bank suggested that the Dept. should undertake a study on piston seals as a part of their project on handpumps.

As a about 25 % of all handpump breakdowns are due to worn out seals, and they are both expensive and laborious to change, the reason for having a special study on them is quite obvious.

The study is based partly on compiled information in the literature etc. and partly on own laboratory results.

The test design used is described and to some extent evaluated. Further on, the use of more simple designs are discussed.
No specific seal material or design is recommended, instead they are described and discussed, within the context of treating the whole below ground assembly as an entity. In many cases seal breakdowns are caused by other reasons than plain wear i.e. the breakdown has been caused by a badly designed system with the effect that the seal is worn out.

PREFACE

This study was started with the main objective to give recommendations for the selection of piston seals for handpump cylinders. These recommendations were to be based on the collected experiences from "the field", i.e different rural water supply projects, pump or seal manufacturers, aid organizations etc. A laboratory study was planned, to back up the information collected.

Soon it was clear that the available information in this case, was very limited, and even worse, no unanimous opinion was to be found regarding the most reliable seal material.

Anyhow, we believe the result to be of some guidance, even if it is difficult to point out one specific material. The study also shows the importance of the following.

1. To consider the sealing function, not only the seal material, i.e. a smooth, non wearing, cylinder wall and possibilities to separate grinding particles.
2. To develop standard procedures for simplified comparable tests of locally available seal materials.

For valuable help during the project, we are greatly indebted to; staff members at Lund University for technical assistance, the Handpump group at the World Bank for views on the work and to Mr Brian Appleton for having scrutinized the report.

Lund in June 1987

Henrik Aspegren
Robert Hahn
Per Johansson

TABLE OF CONTENTS

1. INTRODUCTION

1.1 Background

Laboratory tests of deep well handpump components were started at the department of Environmental Engineering, Lund Institute of Technology, in 1981/82. Tests were performed continuously until 1986. Some results regarding cup seals are given here in section 3.3.

The work was from the start linked to the activities of Sholapur Well Service in India, and thus restricted to deep well reciprocating handpumps. The project was initiated by the Swedish Covenant Church, which also started SWS in India, and therefore not directly a part of the activities of the Water Decade. However, contact was held with the World Bank, Applied Research and Technology Unit, in order to avoid parallel work and to exchange information.

In November 1985, the World Bank suggested a study to be made in Lund, directly as a part of their project "Rural Water Supply Handpumps Project", World Bank/UNDP INT/81/026. The study was suggested to; Prepare guidelines for the selection of handpump piston seals. A project plan was prepared and SIDA agreed to finance the work. In June 1986 the new laboratory test could commence.

The reason for having a special study designed to describe the selection of piston seals, is obvious. The seal is one of the parts of the handpump which is heavily subjected to wear. About 25 % an all handpump breakdowns reported are due to worn out seals. Especially in a deep well the change of piston seals is both laborious and expensive, if special lifting equipment is required. The eventual additional cost for a high quality seal material, would therefore be a good investment. Not less important is of course the increased availability of the pump, with a longer operation time of the seal.

The study is based partly on the compiled experiences from field trials, water supply projects, manufacturers etc, and partly on own laboratory tests. The information which has been possible to attain, is collected in chapter 3, and all test results are collected in chapter 4. The discussion in chapter 5 is made to identify the problems and what we know today, i.e. a sort of state of the art. The intention is not simply to give recommendations or guidelines, but to discuss the alternatives. All basic test data, references, adresses etc are kept as a separate appendix, which can be ordered by those specially interested.

1.2 Scope of Work

The terms of reference stated that the overall objective with the preparation of guidelines for seal material was to:

Improve pump design and performance to enable handpump manufacturers to improve their designs and planners to select the most appropriate handpump for a particular application.

The study should include the following topics: Seal material, seal geometry, single versus multiple seals, effect on seal wear and effects of seal manufacturing methods.

The limitations layed out in the work plan were:

- A restriction to deep well pumps, because they are both subject to more wear, and also more difficult to maintain.
- A restriction to reciprocating pumps and for practical purpose including tests of 63,5 mm cylinders only.
- A selection of 12 seal materials which from experience were believed to show a good result.
- A test procedure implemented by CARL (formerly CATR) consisting of 4000 hours of operation in the test rig.

2. METHOD AND MATERIALS

2.1 Data Collection

Manufacturers, test institutes, distributors and users have been contacted in order to compile information concerning optimum seal design experiences etc.

This collection process could be divided into three steps;

- literature study carried out at the International Reference Centre (IRC), the Hague, the Netherlands.
- letter inquiry
- study visit to India

The literature study is to be found in chapter 3.1. In order to simplify the survey, a matrix is used which broadly classifies the literature. The matrix could also be used as an expanded literature list with special emphasis on handpump seals.

Swedish embassies in developing countries were contacted and asked to provide information on what persons were involved in rural water supply and especially handpump programs. The information given by them formed a basis for sending an inquiry in order to obtain field experience on different seals. An address list is found in appendix D.

In India, a number of pump manufacturers and the UNICEF field test area in Coimbatore were visited.

2.2 Laboratory Test Design

2.2.1 The Test Rig

The present test rig is based on a rig which was built 1982. Although some changes have been implemented the basic structure remains. As can be seen in figure 2.1 the rig is designed for testing 12 cylinders at a time. Furthermore it is divided into three subsystems with four pumps each, thus allowing for the possibility to simulate three well depths by means of pressure tanks and control valves.

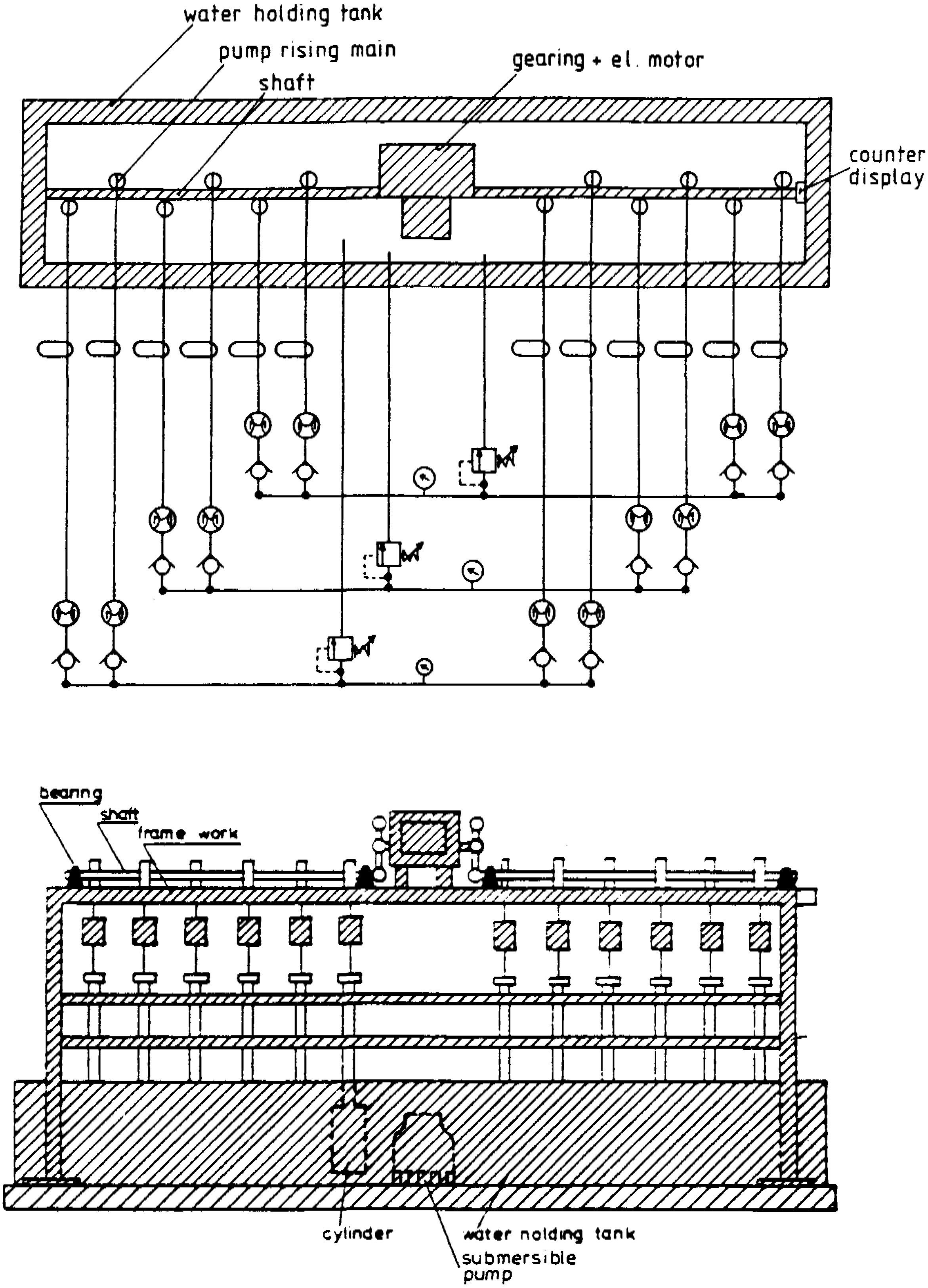


Figure 2.1 The test rig.

The rig is electrically driven and the connections to the 12 pump-rods are evenly distributed on two shafts so that 3 pumps are started every quarter of a cycle, i.e. for each subsystem one pump is started every quarter of a cycle. This provides an even flow to the check valves. The pumping speed is kept at about 48 strokes per minute and the strokelength for all pumps is about 115 mm.

The pressure tanks are equipped with valves for air refill in order to avoid air depletion. The spring operated control valves make possible to adjust the static pressure between 1-8 bar. The submersible pump in the basin is used for circulating the water and thus keeping particles suspended.

In figure 2.2 one single pump is shown. A band is used for connecting the shaft and the pump rod. The band has in previous laboratory tests proved to be superior to the usual chain.

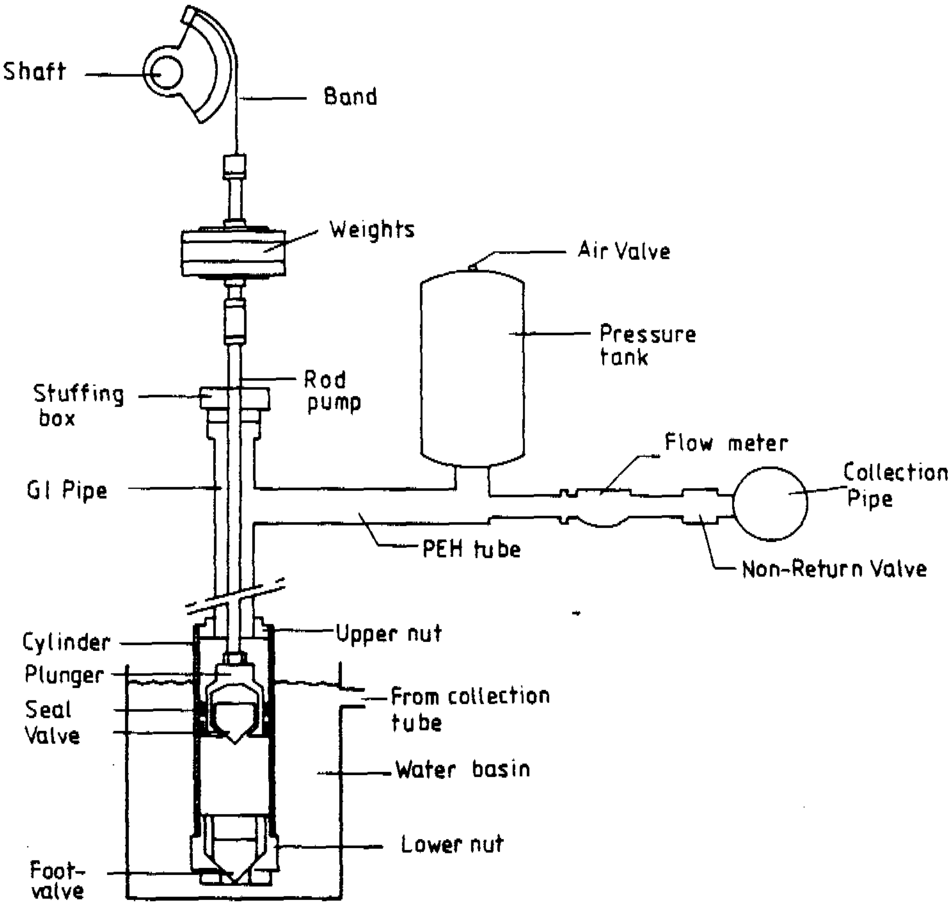


Figure 2.2 One single pump.

The weights needed for the gravitational backstroke are so designed that they can easily be hung on/off where so needed.

From a theoretical point of view the following differences between a full scale pump and the model can be distinguished for clean water.

- The static pressure is created by means of a pressure tank and a control valve.
- The drope pipe has been substantially shortened and is partly of PEH instead of G.I.
- The reciprocating movement of the pump rod is created by means of a motor i.e. the speed of the pump rod could be described by a sinus curve.

As a result of this the dynamic pressure during a pump stroke is altered, mainly due to the motor and the shortened drop pipe, see Appendix B. However this will most certainly not affect the reliability of the results since the test is of a comparative nature.

2.2.2 Comparison Laboratory Test - Field Conditions

Demands on the test equipment have been:

- the operation of the pump in the laboratory should correspond to operation in the field.
- the design should be simple and not require advanced equipment.
- the test parameters should be controlled and constant, i.e. the test should be reproducible.
- the test should be rapid.

Since these demands are contradictory the result is a compromise. For example, results could be achieved faster by keeping a higher pump speed, a longer stroke length and a higher pressure. However, this would imply introducing substantial differences from field conditions and the relevance of the results could be questioned.

The results from the test could be interpreted the following way:

- A bad result in the laboratory means that the detail/material need not be tried in the field
- A good result in the laboratory is promising but must be verified in the field

Since the environment around the pump with changes in climate, temperature, varying use etc cannot be reproduced in the laboratory the operation time in the test rig is not directly transferrable to field conditions. The following estimation suggests that a result is achieved 4-8 times faster in the laboratory than in the field.

average number of users	150-300 persons/pump
average water consumption	15-25 l/p d
maximal pump capacity	0,35-0,40 l/stroke
normal pump speed	30-35 strokes/minute
use	10-12 h/d
reduction factor (varying, use, queues, not full strokes etc)	0,6-0,7

Depending on local conditions the relation between operation time in the laboratory and in the field will be according to the following.

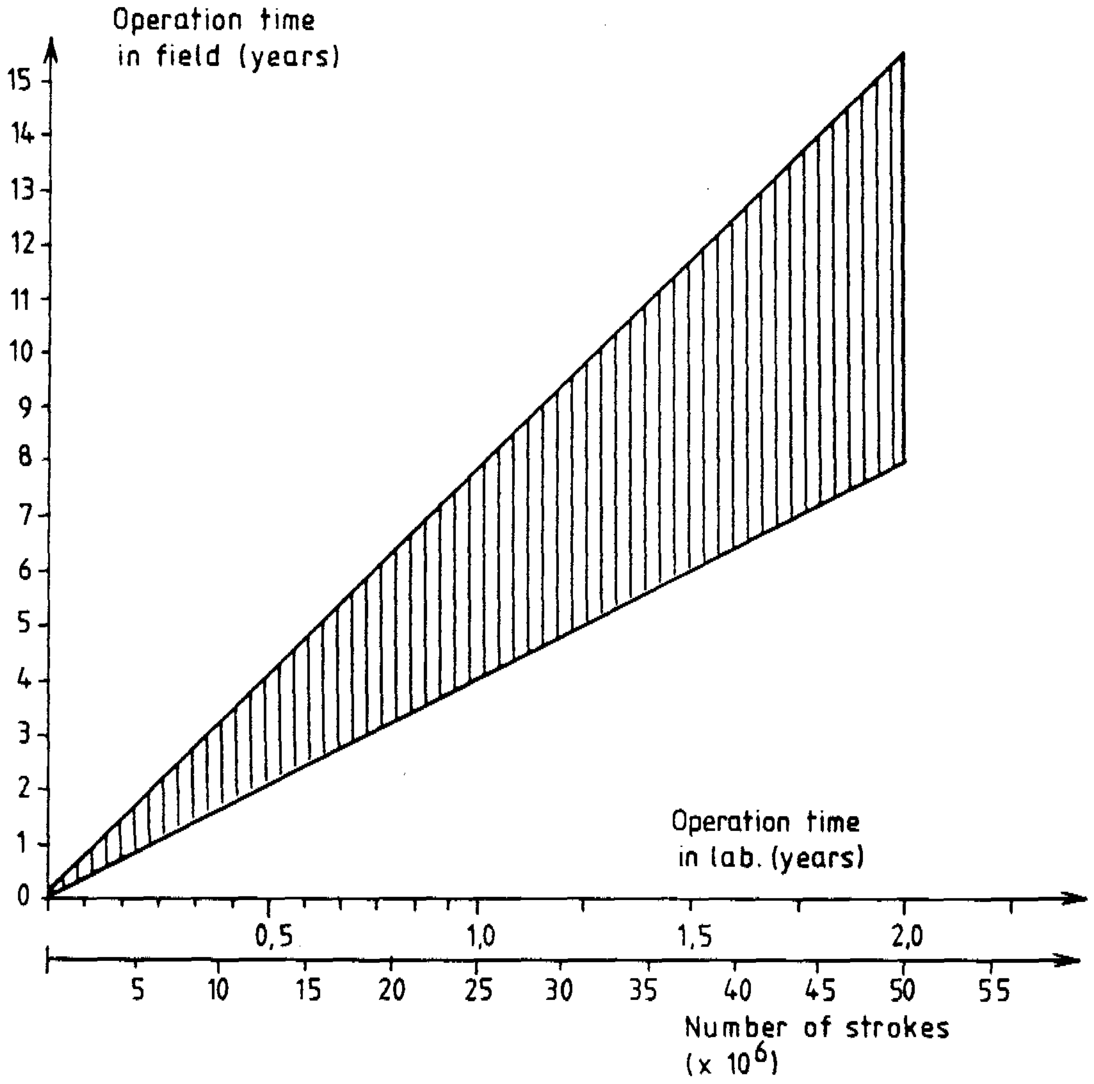


Figure 2.3 Comparison of pump use in the field and in the laboratory.

2.2.3 The Endurance Test

In the following a short description of the endurance test is made. The test program is very similar to the one developed by CARL.

2.2.3.1 Control Program

Below a list of what parameters were monitored is presented.

Once every:

	Day	Week	Month	0 h	1000 h	2000 h	3000 h	4000 h
Number of strokes		X		X				
Stroke length			X	X				X
Flow/capacity		X		X				
Water quality		X		X				
Water temperature		X						
Sureface roughness of cylinder				X				X
Visual inspection of the rig	X			X				
Seal dimensions				X		X		X
Visual inspection of seals				X		X		X
Static pressure	X			X				
Content of particles			X			X	X	X

2.2.3.2 Short Description of Control Parameters

1. Time period:	about 2000 h clean water about 2000 h particle suspension.	
2. Number of strokes:	Since a counter is attached to the rig the number of strokes can be determined for each cylinder. The pumping speed for the test rig can also be determined. See appendix C.	
3. Strokelength:	The strokelength is measured for all cylinders. See appendix C.	
4. Flow/capacity:	The accumulated flow is measured on each of the twelve cylinders. See appendix C.	
5. Water quality:		
pH:	6.5 - 7.5	
Hardness (dHo):	max. 14	
Iron content (mg/l):	max. 0.5	See appendix C
Salt content (mg/l):	max. 500	
Temperature (°C):	20 - 30	
6. Surface roughness:	Measured with a perthometer. See appendix C.	
7. Seal dimensions:	The seals are weighed and measured, see appendix C.	
8. Static pressure:	8 pumps 3 bar, 4 pumps 7 bar.	
9. Content of particles:	1 g/l kieselguhr diam. 7.5 micron 1 g/l sand diam 75 - 500 micron See appendix C.	

2.2.3.3 Test Items

The following materials were tested in some cases the seals have not lasted the whole endurance test in which case the seals/cylinders have been changed. This is seen in the table below where one rig position may have had more than one test item.

Rig Pos.	Static Pressure	Cylinder Material	Seal Material
1	3	Stainless Steel	Swedish leather, vegetable tanning
2	3	Brass	Swedish leather, vegetable tanning
3:1	7	Stainless Steel	Natural Rubber
3:2	7	Stainless Steel	Natural Rubber
4	7	Brass	Swedish Leather Vegetable tanning
5	3	Brass	Swedish Leather Protosile Carnuba
6:1	3	Brass	Nitrile Rubber
6:2	3	PVC	Neoprene
7	3	Brass	Indian Leather Chrome tanning
8:1	3	Brass	Natural Rubber
8:2	3	Brass	Natural Rubber
8:3	3	PEX	Swedish Leather Vegetable tanning
9	7	Brass	Swedish Leather Protosile Carnuba
10:1	7	Brass	Nitrile Rubber
10:2	7	Brass	Indian Leather Vegetable tanning
11	3	Brass	Nitrile Rubber
12	3	Brass	Neoprene

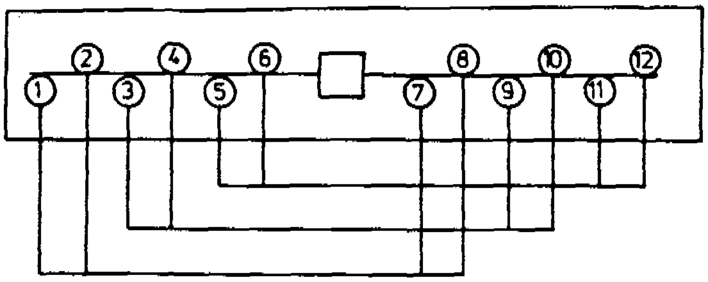


Figure 2.4. Rig positions

In the figure below the seals tested are presented.

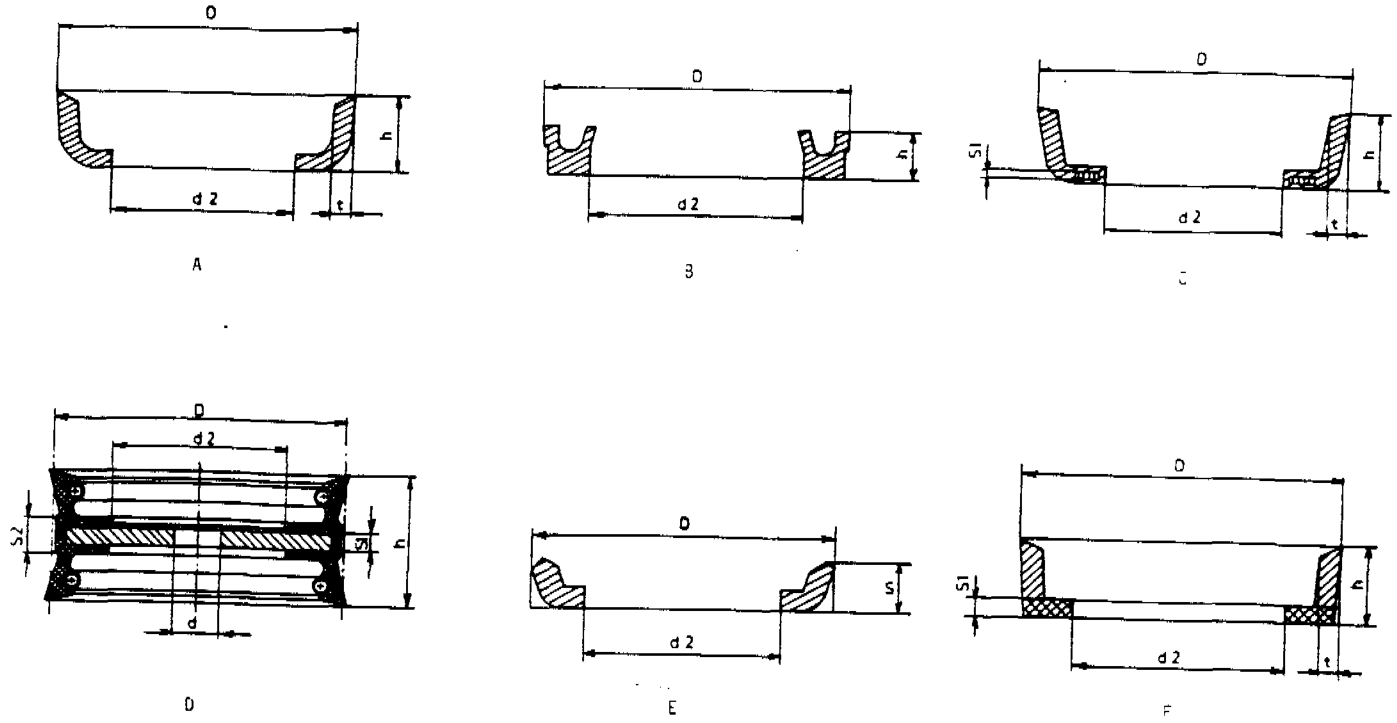


Figure	Position	Material	D(mm)	d2(mm)	t(mm)	h(mm)	S 1(mm)	Comments
A	1, 2, 4, 8:3	Swedish leather Vegetable tanned	60,0	39,0	4,0	16,0	-	
B	3:1, 3:2, 8:1, 8:2	Natural rubber ∿ 60 Shore A	63,0	43,0	-	10,0	-	
A	5, 9	Swedish leather Protosile Carnuba	60,5	39,0	3,5	16,0	-	
C	6:1, 10:1	Nitrile Rubber ∿ 70 Shore A	63,0	38,5	4,5	16,0	1,5	Base reinforced with steel ring
D	6:2	Neoprene ∿ 80 Shore A	63,0	40,0	-	25,0	4,0	
A	7	Indian leather Chrome tanned	61,0	38,0	4,0	15,0	-	
A	10:2	Indian leather Vegetable tanned	63,5	42,0	3,3	17,0	-	
E	11	Nitrile Rubber ∿ 70 Shore A	62,0	42,0	5,0	11,0	-	
F	12	Neoprene ∿ 80 Shore A	64,0	43,0	4,0	16,0	4,0	Base reinforced with textile cord

Figure 2.4 Different seals and their dimensions.

3. LABORATORY AND FIELD EXPERIENCES

3.1 Literature Review

The literature study was to a large extent carried out at IRC. The literature on the subject which is very limited, has been arranged into a matrix in order to give a broad view of the content.

In order to give the matrix a reasonable size only the name of the author and the year of publishing are used. The full report names will be found in the reference list.

The various characteristics of the matrix will be explained to faciliate interpretation.

1. Classification:

This column defines various types of literature:

- Review - briefly informs about different types of handpumps or projects.
- Study - a handpump project is described in more detail and laboratory tests are explained.
- Manual - guidelines are given checklists are formed or formats are presented for laboratory and field tests.
- Article/paper - quotations from different magazines etc.

2. Type:

The report can be distinguished as either having:

- An analytical approach, i.e. of an explanatory character.
- A descriptive approach.

3. Project:

The results in the report/paper could originate from either:

- A laboratory study
- A field study/evaluation

4. Pump Range:

Defined as;

- A shallow well pump: 0-10 m depth.
- A deep well pump: >10 m depth.

5. Cylinder Material

Apart from commonly used materials, the group "Others" include different plastic cylinders or special liners or coatings.

6. Seal Material:

The following classification is used here

- Leather - including different tanning and post treatment processes
- Rubber - commercially available types.
- Other materials - other synthetic material than rubber; plastics and experimental seal samples.

7. Results on seal materials:

Whether the report presents any results on seal materials

8. Recommendations:

Whether any recommendations concerning design, material etc. are made.

	1. Classification				2. Type		3.Project		4. Pump Range		5. Cylinder Material					6. Seal Material				
	Review	Study	Manual	Article/ Paper	Analytical	Descriptive	Lab.	Field	Shallow	Deep	Cast Iron	Brass	PVC	Stainless Steel	Other	Leather	Rubber	Other Material	Results on Seal Materials	Recommendations
Arlosoroff et.al(1985)	X	X	X		X	X	X	X	X	X	X	X	X			X	X		X	X
CATR, (1982)	X	X				X	X		X	X	X	X	X			X	X	X		
CATR, (1983a)			X			X	X													
CATR, (1983b)		X	X		X	X	X		X	X	X	X	X			X	X	X	X	
CATR, (1984)	X	X	X		X	X	X		X	X	X	X	X		X	X	X	X	X	
CATR, (1986a)	X	X	X		X	X	X		X	X		X	X	X	X	X	X		X	
CATR, (1985b)		X				X	X			X						X	X		X	
Crown Agents (1987)		X			X	X		X		X		X	X			X	X		X	X
Fannon et.al (1970)		X			X	X	X		X	X	X	X				X	X	X	X	X
Fannon et.al (1975)			X				X									X				X
Frink et.al (1967)		X			X	X	X		X	X	X	X			X	X	X	X	X	X
Govt. Bangladesh(1985)		X	X		X	X		X	X				X			X	X		X	X
Guindo (1986)		X			X	X		X		X		X	X			X	X	X		X
Hahn (1983)		X			X	X	X			X		X								
Hahn (1985)		X	X		X	X	X			X		X			X	X	X		X	
Hofkes et.al (1986)		X	X		X	X			X	X										X
IDRC (1984)				X		X			X				X			X	X			
IRC (1979)	X					X														
IRC (1981)	X					X														
IRC (1982)	X		X			X			X	X										
IST (1984)			X			X						X				X				X
Kigingi (1984)		X			X			X	X			X								
Malila et.al (1979)		X				X	X		X				X			X				

	1. Classification				2. Type		3. Project		4. Pump Range		5. Cylinder Material					6. Seal Material				
	Review	Study	Manual	Article/ Paper	Analytical	Descriptive	Lab.	Field	Shallow	Deep	Cast Iron	Brass	PVC	Stainless Steel	Other	Leather	Rubber	Other Material	Results on Seal Materials	Recommendations
Nimityongskul (1982)	X	X				X	X						X				X		X	X
Potts et.al (1979)		X				X		X	X	X	X	X	X		X	X			X	
Potts et.al (1981)	X					X														
Potts et.al (1984)		X				X	X						X			X			X	
Prasad (1979)	X	X	X		X	X	X	X		X		X				X			X	
Rogers (1984)				X		X		X	X				X			X	X		X	
RWS Handpump PT (1986)			X			X														X
Sharp (1982)	X	X			X	X	X	X	X				X			X	X		X	
Subba Rao et.al	X	X				X	X		X		X		X		X	X		X	X	X
Tschannerl(1985)	X	X	X		X	X	X	X	X	X									X	
Veturlidason (1983)		X			X	X	X			X		X								
WHO (1976)	X	X	X			X		X		X					X		X		X	X
Yau (1985)		X	X		X	X	X	X	X				X				X	X	X	

3.2 Results and Recommendations

In this chapter results and recommendations in the literature and elsewhere will be briefly reviewed.

Arlosoroff et al. (1985)

Based on field and laboratory experiences, it is recommended to use high quality leather seals, while synthetic or natural rubber ones have not been sufficiently tested to permit an evaluation of the performance in relation to leather. The advantage of two or more seals has also not been demonstrated.

Crown Agents Service (1987)

Mr N.S. Prasad reports from a field test of 55 handpumps in Coimbatore, India. An analysis of the results gives that:

1. The life factor of the seals is higher in the pumps where a particle separator is fixed.
2. The average life factor recorded for vegetable tanned seals is two times that of chrome tanned seals, used in standard cylinders.
3. The average life factor of a vegetable tanned leather seal is four times higher than that for a chrome tanned one, when pumps with a particle separator are used.
4. The life factor of a nitrile rubber seal is two times that of a vegetable tanned leather seal.
5. The intake pipe of 2" diameter, 60 cm long was found to be ineffective.

Fannon et al (1970)

Lab testing of five different seal materials.
Materials tested
1) Rek - Syn
2) Vix - Syn
3) Corfam

   A) thin Corfam coated with graphite
   B) medium flexible Corfam impregnated with wax and coated with rubber
   C) stiff Corfam

4) Rulon
5) Leather

   A) oak-tanned
   B) chrome-tanned

Based on the laboratory tests the following conclusions were reached concerning the selection of seal materials.

1) Wax-impregnation of leather is one of the major factors in extending the life of leather cup seals because the leather tends to remain soft whether wet or dry.
2) Wax- impregnated Corfam cup seals of the proper flexibility, coated on the outside with nitrile or urethane rubber, will provide better performance than the best leather cup seals.
3) The major factor, limiting the performance of cup seals made from other materials is the reduced ability of the materials to stretch and conform to the cylinder walls as compared with Corfam and leather.

Fannon et al (1975)

Good quality leather is recommended for making cup seals. Dyes should not be used, however, wax impregnator is acceptable.

Frink et al (1967)

Lab testing of different seal materials and cylinder materials. The surface roughness of the cylinder is recognized as being of major importance for the wear of the seals. It is also concluded that leather seals are superior to synthetic seals because of the wide tolerances permissible in the manufacture of the cups.

Govt. of Bangladesh et al (1985)

In the report of the workshop on the design of the Tara handpump, it is agreed on the following details regarding the cup seal for 2" cylinder.

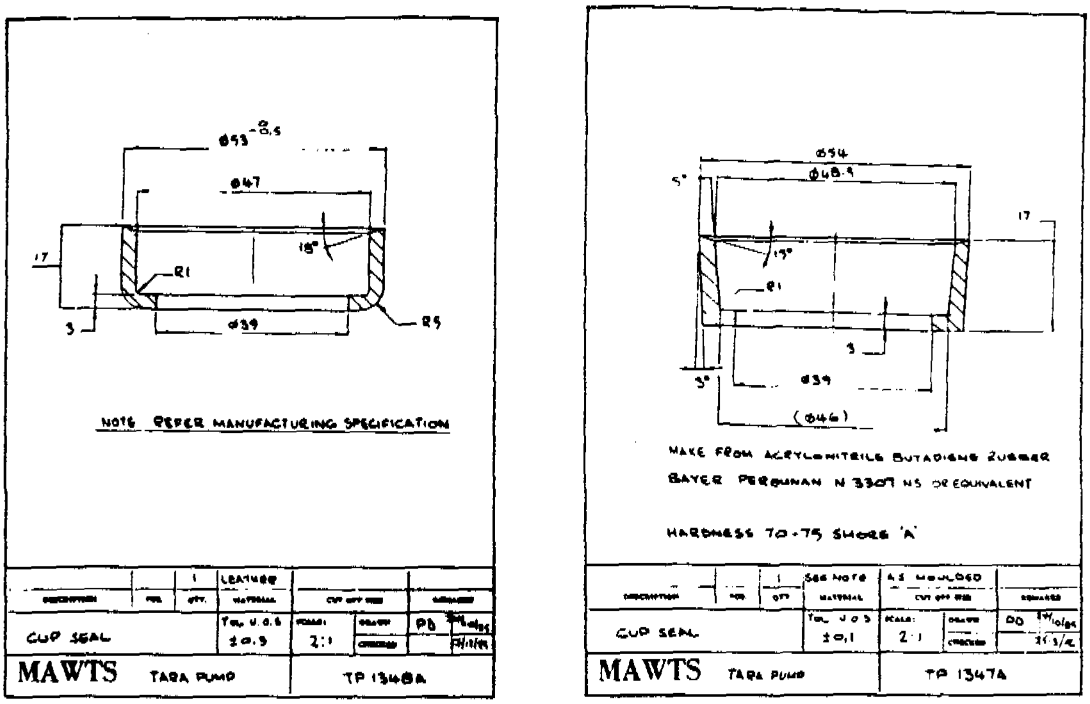


Figure 3.1 Recommended dimensions.
a) leather
b) nitrile rubber

It is reported from the Mirzapor field study that the seal is the most frequently replaced item. Lab testing at CARL showed that leather cup seals failed when abrasive materials were present in the water, but nitrile rubber seals survived the test uneventfully.

Hahn et al (1985)

Lab investigation of different seal materials. It is concluded that leather is a comparatively good material for cup seals. If the leather is chosen properly and properly treated the leather seal may last as long as any synthetic material. However the quality varies from one seal to another. Dimensions for leather seals are also given.

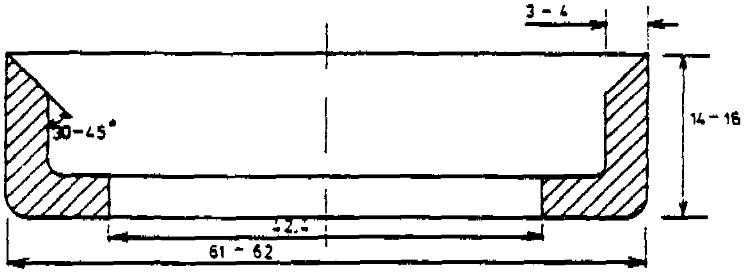


Figure 3.2 Recommended dimensions.

Hofkes et al. (1987)

Only general statements are given such as "cup seals should be of wear-resistant materials, non-toxic" etc, and that impregnation may improve the leather seal and that PVC and neoprene appear to have longer service life. It is also stated is that one piston seal is sufficient down to 50 m of depth.

Indian Standard Institution (1984)

The specification for deep well handpumps 15:9301, advises for the India Mark II type only dimensions of the seal and that the material is leather.

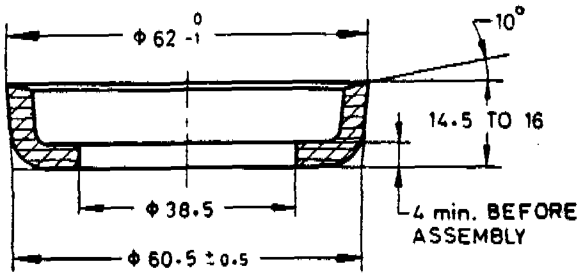


Figure 3.3 Recommended dimensions

Malila (1979)

Laboratory testing of a PVC pump. Polythene cup seals could replace leather cups for better performance and less replacement.

Nimityongstul (1982)

Laboratory testing of the Waterloo PVC pump. Polyethylene rings are preferred to leather cup seals as the frictional resistance is less with them.

Prasad (1979)

From a field observation of 32 pumps in Karnataka, India and own laboratory tests, Mr Prasad concludes that leather performed better than synthetic materials tried. Measurements of swelling showed that vegetable leather takes up less water than chrome tanned leather does. The raw material is also important. Backbone, butt and shoulder parts of the hide should be used.

Rural Water Supply Handpumps Project Team (1986)

In this draft sample bidding documents for the procurements of handpumps, some technical specifications are given. It is stated that if abrasion from sand particles may occur, nitrile or other plastic seals should be specified.

WHO (1976)

Laboratory test. Neoprene is concluded to be a suitable material for the cup seal (acrylo - nitrile rubber may be better). The diameter of the washers should provide a 0,2 mm clearance fit.

Wollschied

Mr Wollschied of IGIP in Ghana reports on Clayton Mark 707 graphite Cup Seals. More than 2000 Clayton Mark 442 full brass cylinders have been monitored, the average installation depth is 24 meters and the approximate use is 6-10 hours per day. In the figure below the percentage of unreplaced seals is plotted against the operation time.

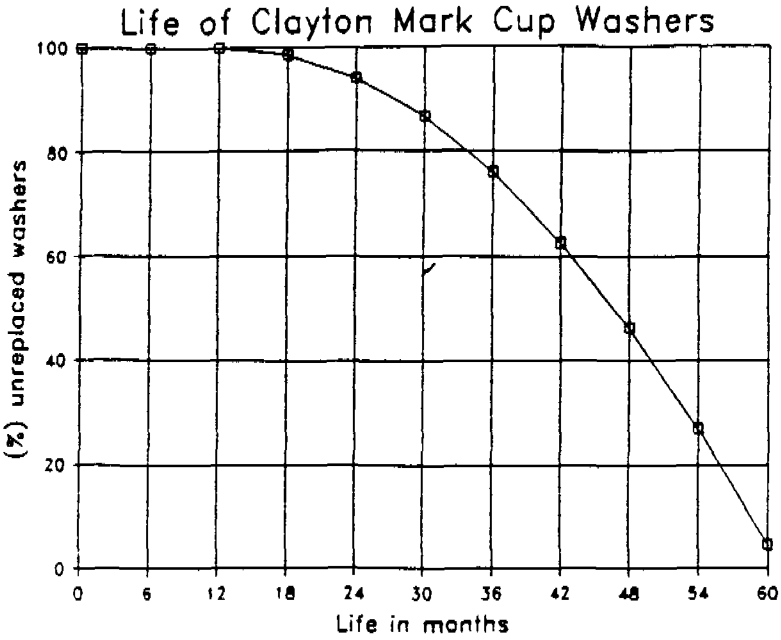


Figure 3.4 Percentage of unreplaced seals versus operation time (IGIP).

3.3 Previous Laboratory Test

Earlier tests were made with basically the same test design, as described in section 2.2. The simulated well depth was 30 m, and the test was continued in each case, until the seal was completely worn out. No particles were added to the water except for those resulting from wear and abrasion of the equipment. All cylinders were made of brass or with a brass liner.

3.3.1 Synthetic Materials

A few synthetic materials were tested, all except one with poor result. A rubber seal performed very well. The quality was 85° shore, nitrile rubber, with the design showed below. After 50 million strokes the operation was still satisfactory, even if the edge of the sealing lip was worn down.

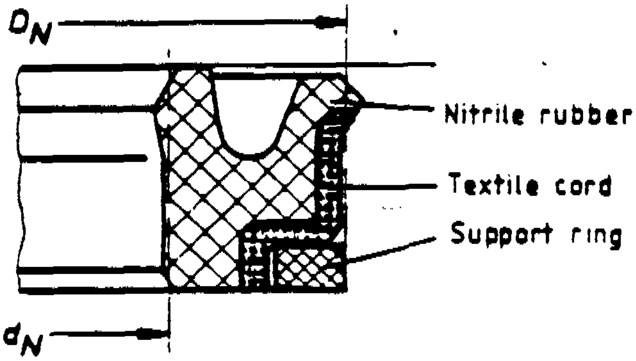


Figure 3.5 Nitrile rubber seal.

3.3.2 Leather

Different cup seals manufactured in India and in Sweden were tested. The operation time varied from 8 to over 50 million strokes. Some conclusions can be drawn from the test:

A: The leather cup should be relatively stiff.

A stiff leather cup will mainly wear at the upper part, thus decreasing in height with time. Note however the risk of a getting the seal stuck in the cylinder, due to swelling.

A soft leather will tend to buckle out at the lower part and be worn through there, giving it a comparably low operation time. This can be overcome by having a support ring under the seal or very little free space between piston and cylinder wall.

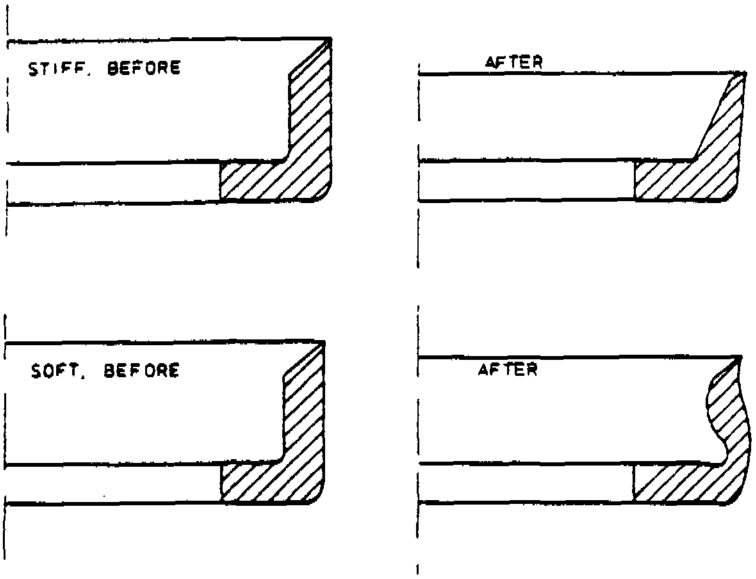


Figure 3.6 Deformation of stiff and soft leather cups.

B: The raw material of the leather cup is most important.

The test did not indicate any difference between the tanning processes, but a most significant difference regarding the origin of the leather. In this case the Swedish leather was known to be of good quality from one supplier and the Indian leather came from several different suppliers. The Swedish samples were both vegetable and chrome tanned and in two cases a combination of the two.

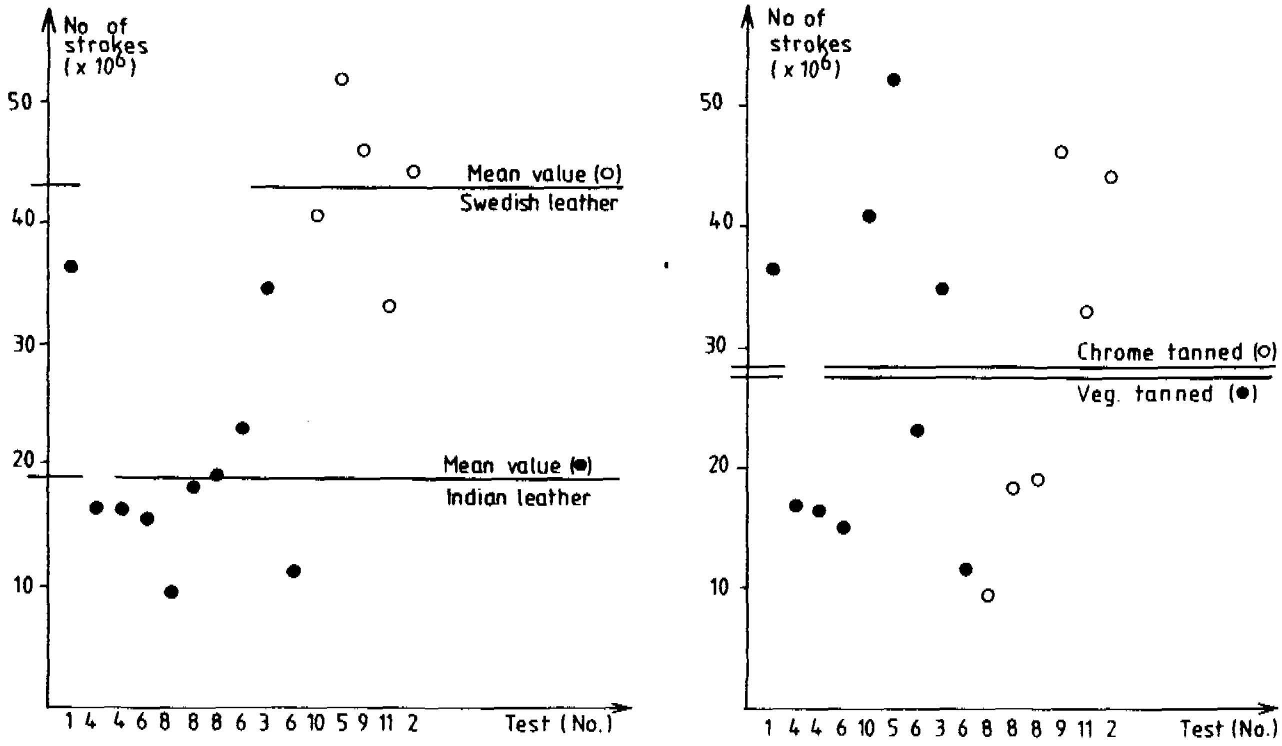


Figure 3.7 Operation time for leather cups.

C: Impregnation is of minor importance.

This statement is not well proved, but the opposite could not be proved either. Some of the items were said to be treated to prevent excessive water uptake, but showed no different behaviour except for a sticky coating after some time of operation. However, a hard wax like Carnuba, with a high melting point, will probably be more resistant.

D: The grain side of the leather should be turned inside.

The most dense and fibrous layer of the hide is near the grain side. If this is turned inward the cup, the stability will last longer even after some wear. The test showed that cups with the flesh side outward rapidly adapted to the cylinder wall and developed a surface as smooth as the grain side.

E: With multiple seals, the wear is equal for the upper and the lower seal.

Table 3.1 Wear of upper and lower seal.

Type of leather	Most worn cup seal Upper	 Lower	 Equal
Stiff	5	2	4
Soft	1	3	0
Sum	6	5	4

The table shows that in about 70 % of the cases the lower seal is equally or more worn than the upper one. Theoretically this was not expected. The reasons could be that:

- The seals are not entirely centric, which gives leakage through the upper seal.
- Eccentricity gives wear at certain points, also at the lower seal.
- Particles get stuck in the upper seal and opens a passage for water down to the lower seal.
- Uneven quality between the two samples.

Irrespectively of the reason or reasons for this difference, it is at the same time a motive for having multiple seals to get a improved reliability.

F: The cylinder material is most important

To facilitate evaluation of the result, the same cylinder material, brass, was chosen in all tests. One exception was made, however, test 1 as shown in figure 3.10. This cylinder was made of crossbounded polyethylene. This material was selected because it has a smooth surface and is more abrasive resistant than common HDPE and similar materials. The leather cups were of the same type as in test 4:1, 4:2, and 6:1. Note that no wear at all was recorded, while in the other samples the operation time was even, below 20 million strokes. After 40 million strokes in the plastic cylinder the thickness of the leather cups had increased, probably due to compression of the fibrous layers during the up-strokes.

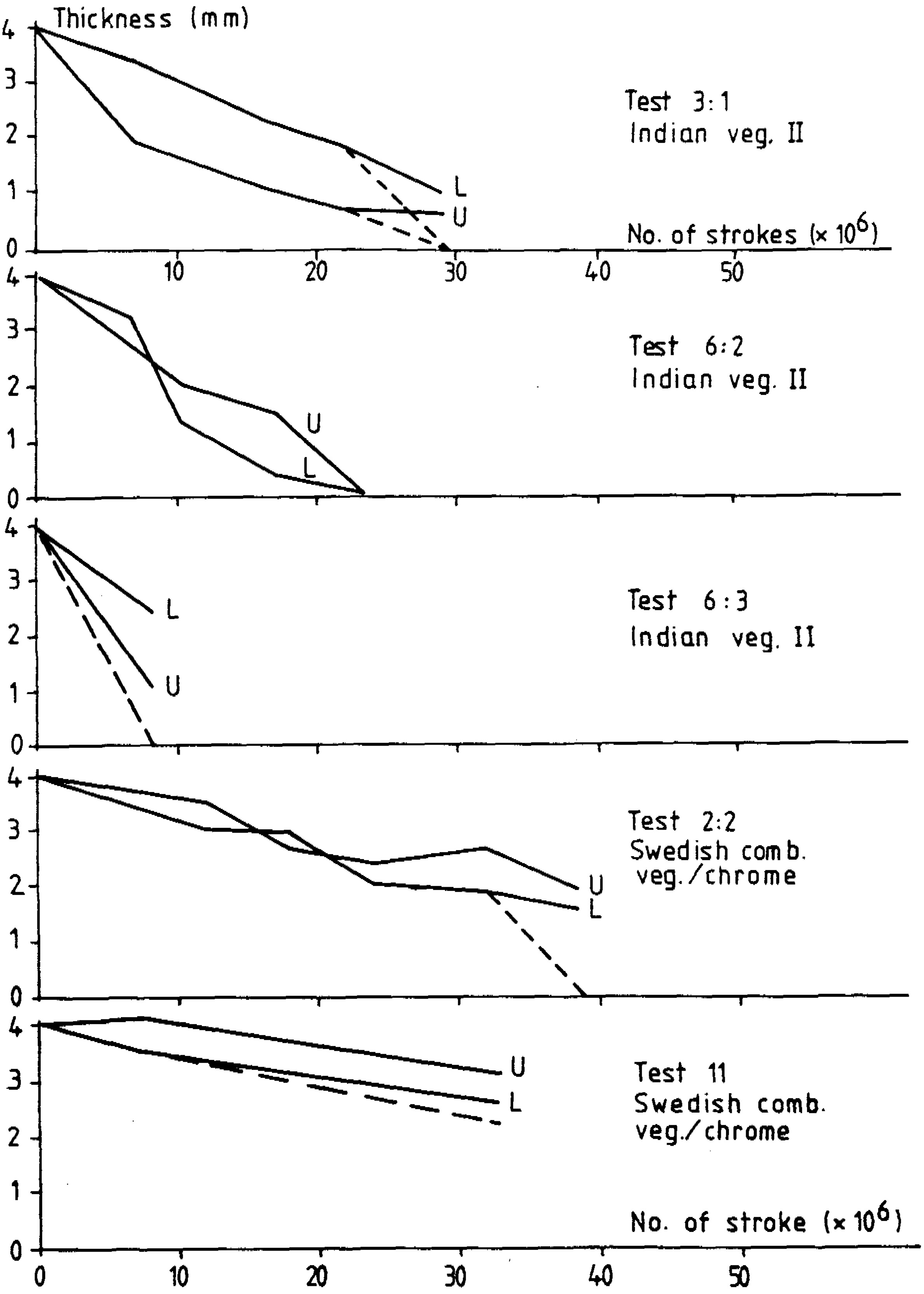


Figure 3.8 Wear of leather seals
U = upper seal
L = lower seal
The broken line shows the minimum thickness at some point (often zero, i.e. totally worn away).

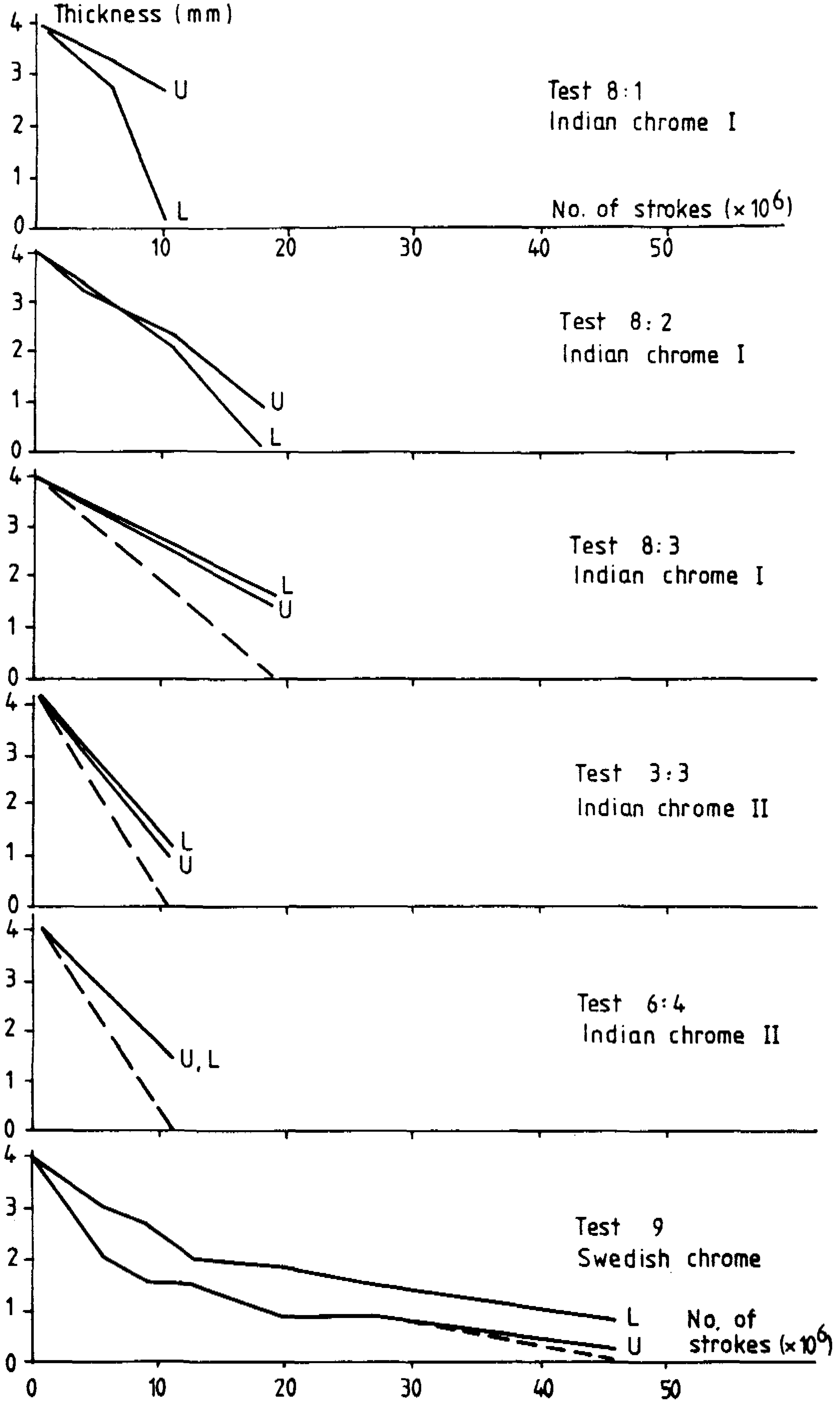


Figure 3.9 Wear of leather seals

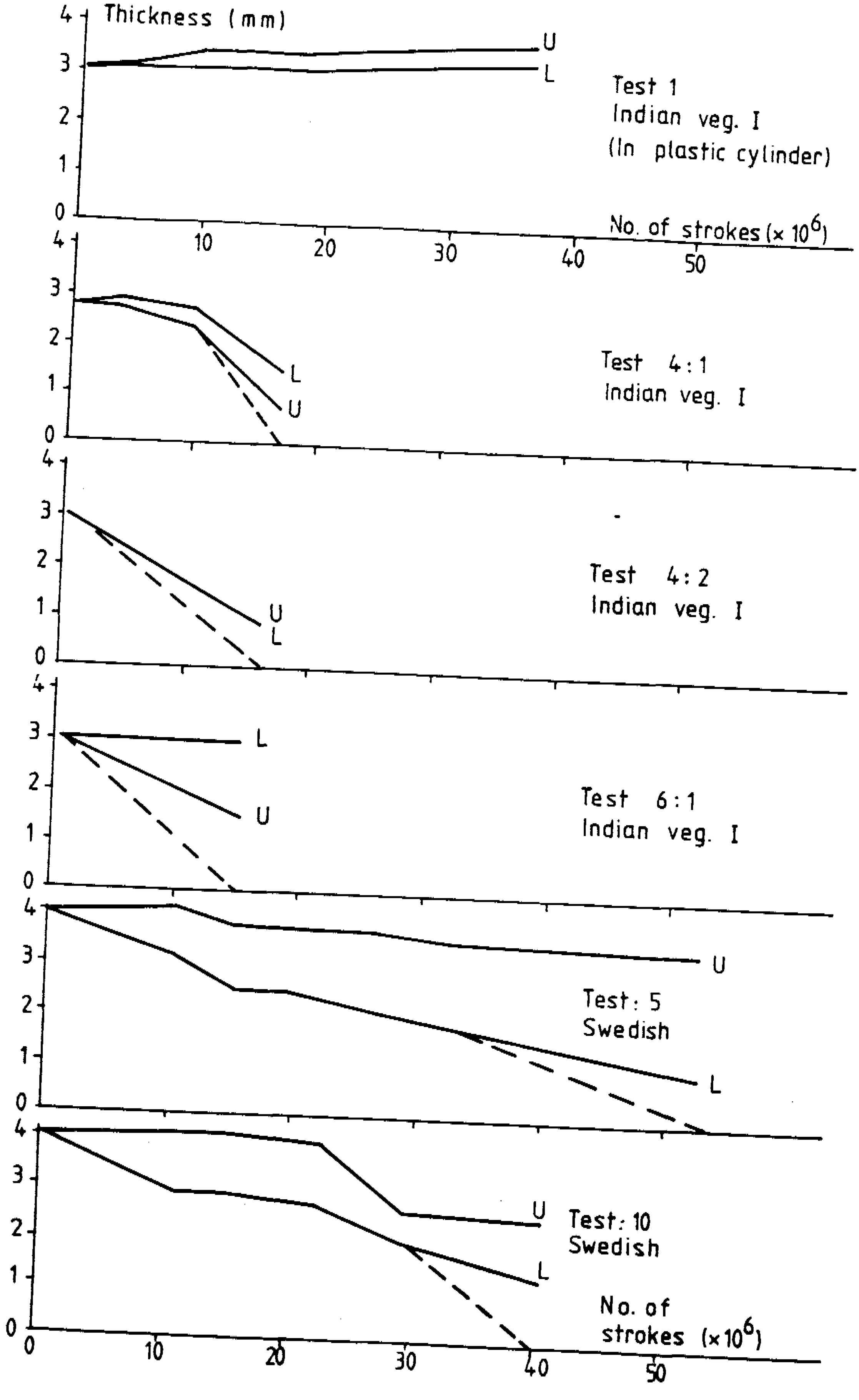


Figure 3.10 Wear of leather seals

4. RESULTS

In the following the results from the laboratory test will be presented. As a measure of seal wear, the change of volume has been chosen .The mean volumetric efficiency, which is also presented, gives an idea on how the pump has worked during the test. In appendix A this is shown more in detail.

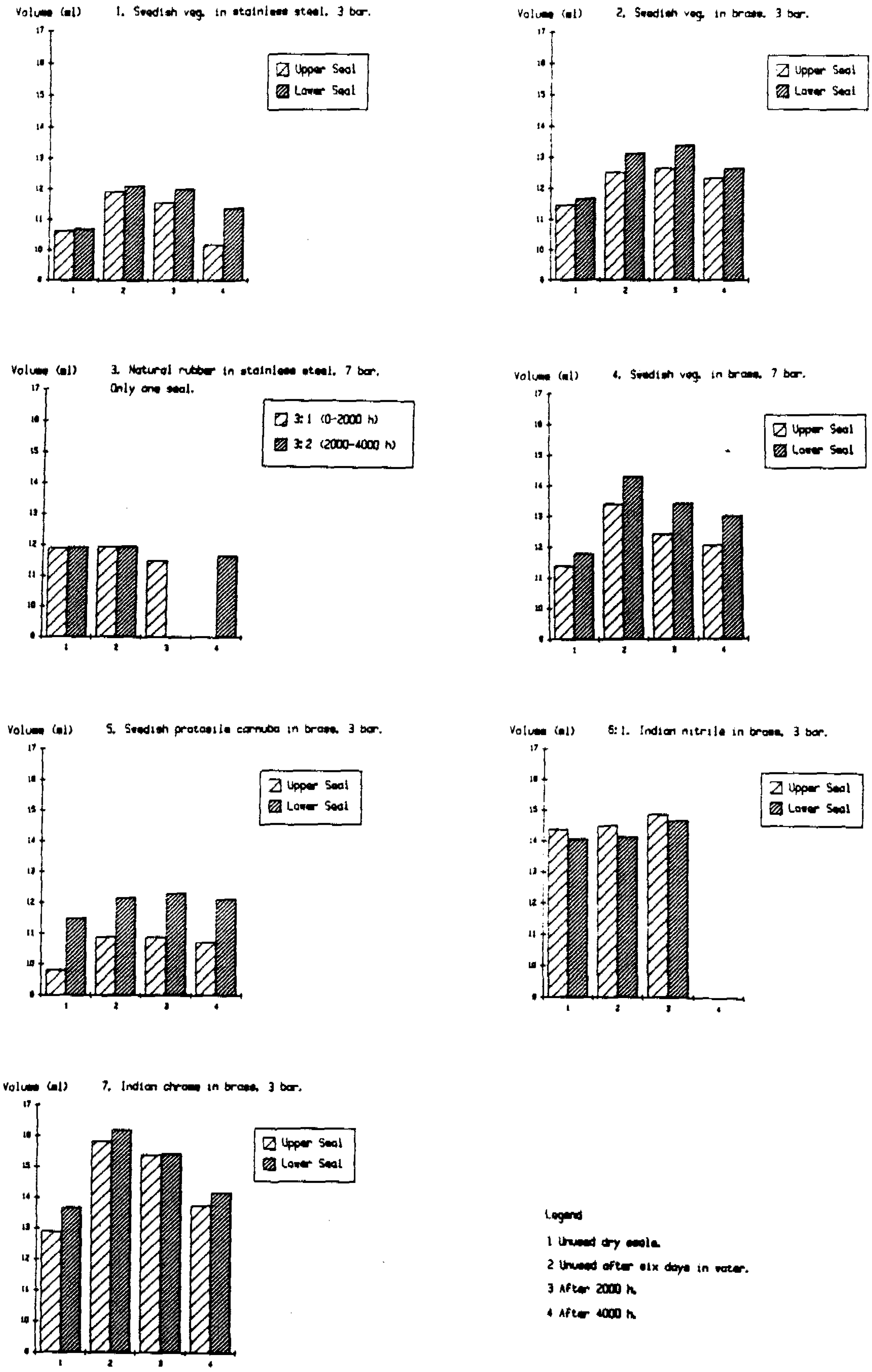
The weekly value is measured over one week, whereas the discrete value indicates the efficiency at a specific moment.

The volumetric efficiency was calculated the following way.

Volumetric efficiency = $q/V*100$

q = Volume per pump stroke

V = stroke length * cylinder area = bucket volume


1. Swedish veg. in stainless steel. 3 bar.

2. Swedish veg. in brass. 3 bar.

3. Natural rubber in stainless steel. 7 bar. Only one seal.

4. Swedish veg. in brass. 7 bar.

5. Swedish protosile carnuba in brass. 3 bar.

6:1. Indian nitrile in brass. 3 bar.

7. Indian chrome in brass. 3 bar.

Legend

1 Unused dry seals.

2 Unused after six days in water.

3 After 2000 h.

4 After 4000 h.

Figure 4.1 Change of volume

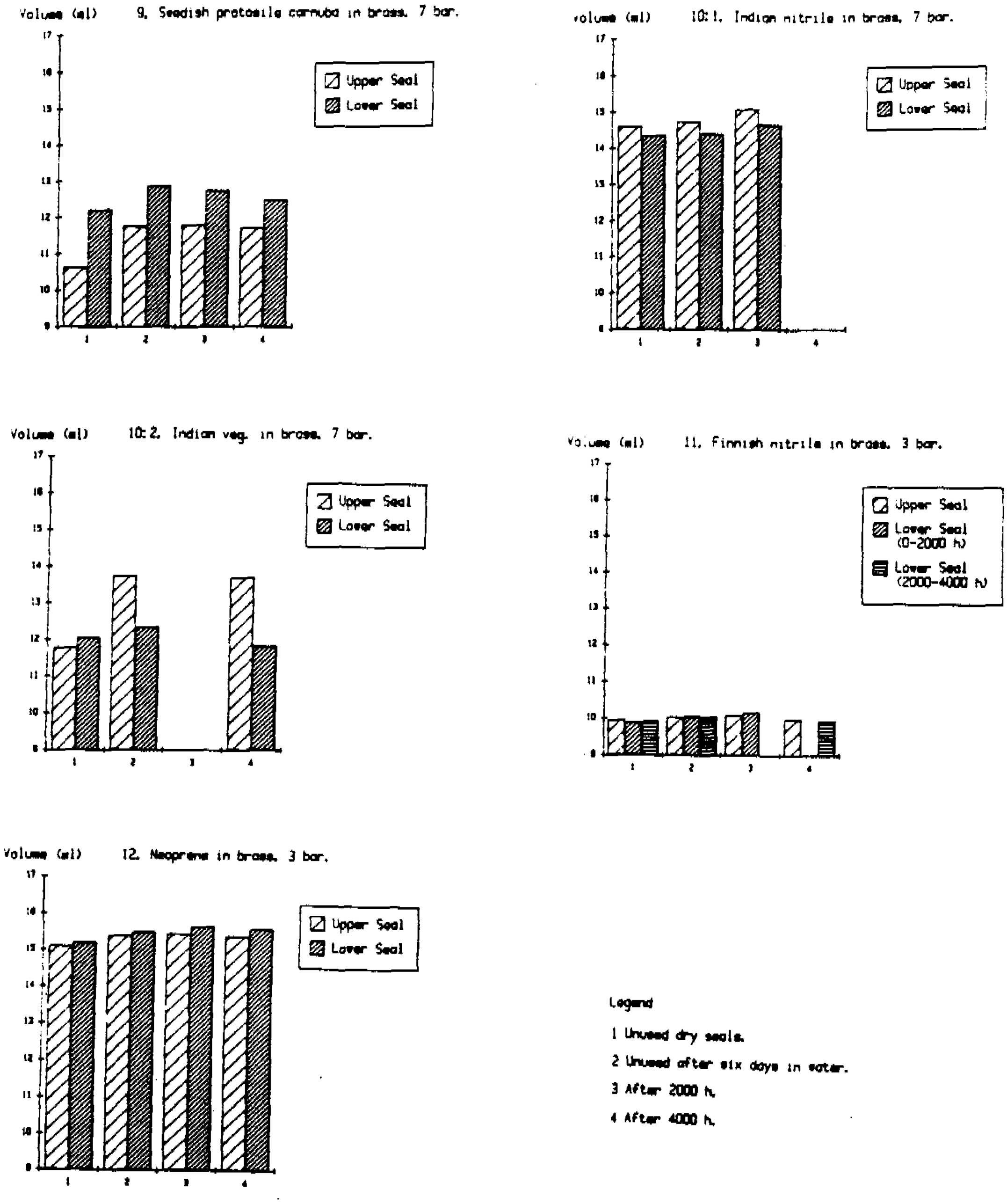


Figure 4.2 Change of volume

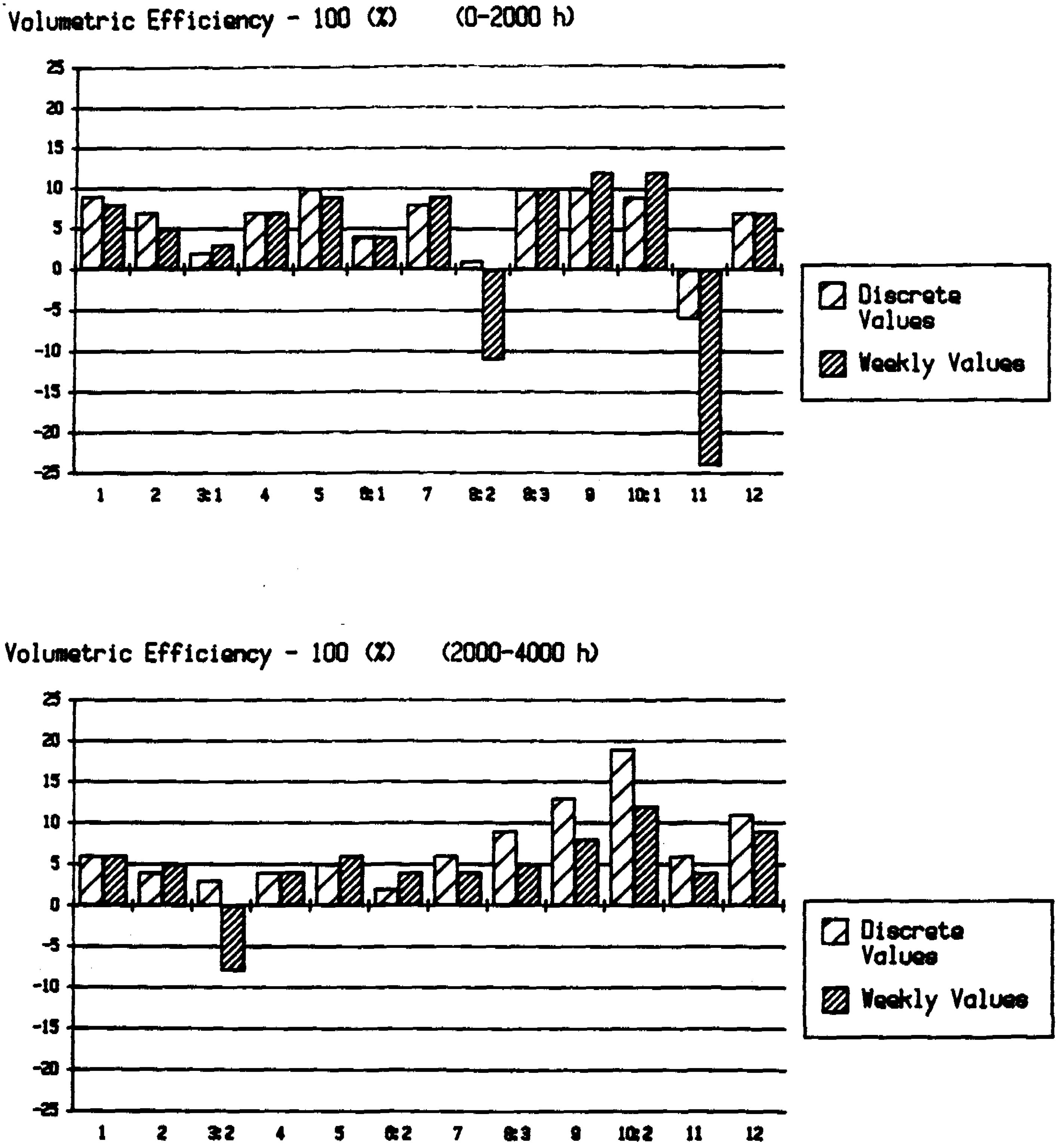


Figure 4.3 Volumetric efficiency

4.1 Seal Wear

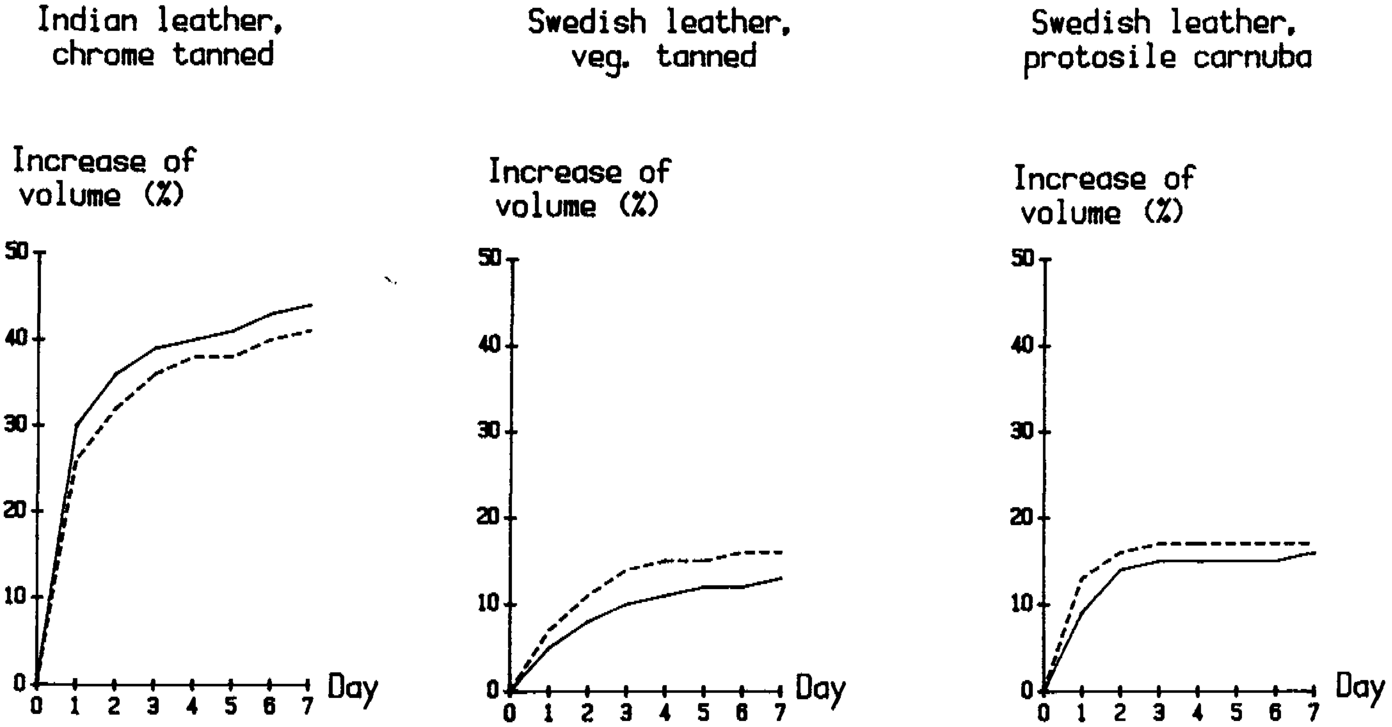
As most of the seals for the test were chosen because of their ability to resist wear and the time period 4000 h is a relatively short time, most of the seals were in a very good state at the end of the test. The seals which did not last the whole test period were in most cases changed for other reasons than wear. In the previous tests the seals have been run until they have been totally worn out i.e. the test has yielded the operation time of the seal. In this test only the change of volume etc could be determined. This is of course not a satisfactory basis for predicting the operation time of a seal and as the wear was quite negligible it is not possible to rank the different seal materials.

However the seals which lasted the 4000 h without problems can all be said to have performed well. Of the new materials tested, the neoprene seals seemed to work as well as or better than the leather seals.

Below a list follows; why different seals were changed:

- The Indian nitrile rubber seals were changed after 2000 h as they were ripped apart along the interior steel ring, see figure 2.4.
- The lower Indian vegetably tanned seal was torn apart along its base.
- The lower finnish nitrile rubber seal slipped out of its fixed position and was consequently deformed and therefore changed after 2000 h.
- The natural rubber seals in brass cylinder turned inside out after a few days in operation. In stainless steel cylinders problems occurred after 2000 h when it was discovered that the piston had cut into the seal and hence destroyed it. This was due to the fact that the lower part of the piston had scored the cylinder wall and a sharp edge had been formed on it which later destroyed the seal. The second seal which lasted the remaining 2000 h was heavily worn after the test probably because of the scored wall.

Leather seals swell when submerged into water. The major increase in volume takes place within the first 6 days. The volume after six days may increase with up to 40 % of the original volume. It must be noted though, that the increase of volume varies both in time and in size for leather of the same quality, see figure 4.4.



Indian leather, chrome tanned

Swedish leather, veg. tanned

Swedish leather, protosile carnuba

Figure 4.4 Swelling of different seals, two samples in each case.

Rubber seals swell for a very long time but to an extent which could be considered negligible from an operational point of view.

The pressure does not seem to have affected the wear substantially but seal deficiencies are faster detected at a higher pressure. If the test would have been continued the pressure would probably have affected the seal wear.

The sand has probably increased the wear of the seals but to what extent this will affect the operation time is impossible to determine.

It cannot be concluded that only the upper seal is working.

As for different cylinder materials further testing is needed before any conclusions can be drawn.

The volumetric efficiency is for most pumps higher than 100 %. In the cases where it is lower this has had to do with malfunctioning valves.

4.2 Cylinder Wear

In table 4.1 the surface roughness can be seen.

Table 4.1 Surface Roughness, cut off length 0,8 mm.
R_a = Arithmetical surface roughness (μm)
R_F = Maximal surface roughness (μm)

	Before Test		After Test	
	R_a	R_F	R_a	R_F
Brass	0.3	3,3	0,2	1,7
Stainless steel	0,1	1,0	0,3	2,4
PEX	0,6	2,3	0,3	3,5
PVC	0,5	3,5	0,3	3,4

As can be seen from the table above the surface roughness is very similar for the different materials tested and within acceptable ranges both before and after the test.

On the macro scale, axial grooves had been formed in all cylinders, especially the plastic cylinders had some quite deep ones.

No difference in wear or scoring of the cylinder walls could be seen for different seal materials. It can not be concluded that leather seals will score the cylinder walls more than rubber seals.

5. DISCUSSION

5.1 Available Materials

5.1.1 Leather

5.1.1.1 Raw material

Hides and skins, the term hide is applied on big animals, from animal and man basically consist of three layers, see figure below;

O) Epidermis
L) Cutis, Corium, leather skin
U) Subcutis, flesh

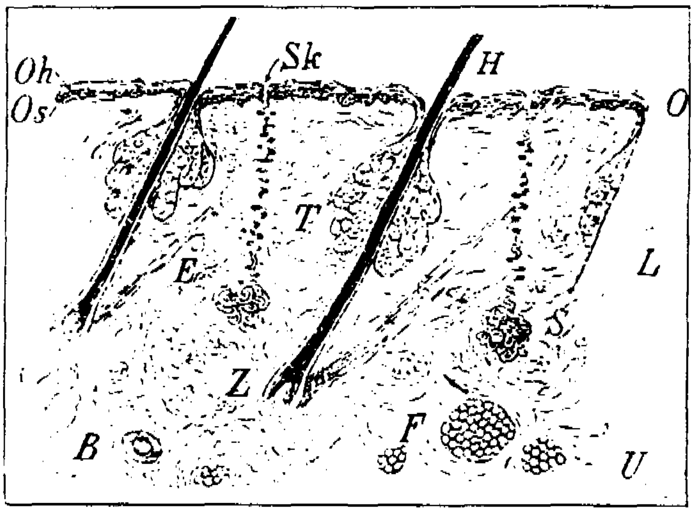


Figure 5.1 Hide Structure

Epidermis is thin, about 2 % of the total thickness and consists of epithelial cells.

Cutis mainly consists of intertwined threadlike tissue, but there are also numerous sweat-glands and sweat-canals. By treating the leather skin, as cutis is often called, with tanning-agents it is possible to transform it into leather. The part of the leather skin which borders on epidermis is called the grain.

Subcutis mainly consists of fat cells veins, and tissue and constitutes the part which connects the skin to the rest of the body. This part is usually called the flesh and is removed before tanning.

Hides and skins differ in structure, depending on habits of life of the animal, season of year, age, sex, breeding and from which part of the hide it originates.

Cattle hide gives a firm leather. The thickness increases with age and is bigger for an oxe than for a cow. Calfskin is denser and yields a higher strength as it does not contain the same amount of fat glands. As a rule, leather from the butt yields the best quality, see figure 5.2.

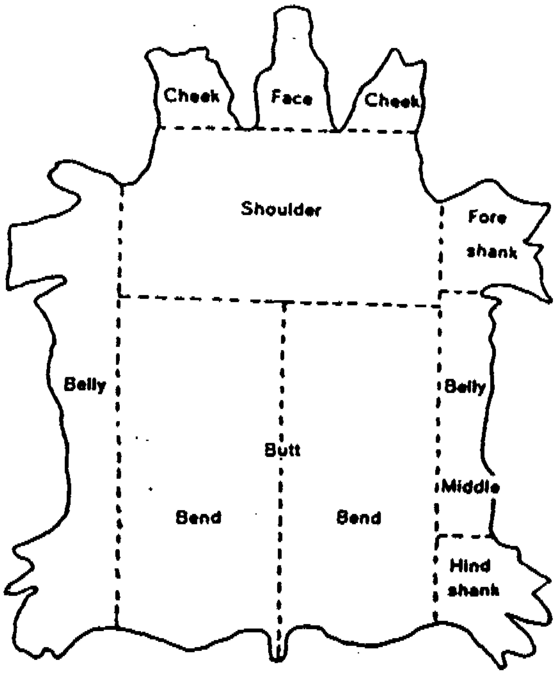


Figure 5.2 Nomenclature for cattle skin

Sheepskin is open and porous and has little structural fiber. This lack and the concentration of glands in the area at the base of the hair root, result in physical weakness of the skin at this point.

Goatskins have a tighter fiber structure and is stronger than sheepskins.

Horse hides are divided into two parts. At the top of the hindquarters the skin is thick and the fiber structure is very dense. Leather of this quality is called "shell cordovan". The rest of the hide is of a lower quality.

The primary condition in order to produce leather of good quality, is thus to select raw material suitable for the application, i.e. the right type of animal and the right part of the hide.

5.1.1.2. Pre Treatment

The first step when taking care of a fresh hide from a slaughtered animal, is to stop the process of decay. Bacterial decomposition of the hide will start within a few hours. In order to stop this and preserve the hide until it can be tanned different curing systems are used e.g. drying, salt curing and brine curing.

Drying is simple especially in hot climates, but the method requires cautiousness. If the drying is too fast, the outer surfaces of the hide may become dry, while the inner parts still have enough moisture to support bacterial growth and the hide may rot out from the inside. The use of salt has a moisture absorption and bactericidal effect. It is, however, important not to reuse the salt or other chemicals as they may pollute or introduce strains of bacteria which will cause decay.

In order to prepare the hide for tanning a number of processes are necessary.

* Soaking as a means of rehydration.

* Liming in order to remove hair, epidermis and accomplish a swelling of the leather skin which will make it more receptive to tanning-agents.

* Deliming, the removal of alkali and the adjustement of pH for bating.

* Bating, an enzymatic action for the removal of unwanted hide components. The undwanted components consist of some of the protein degradation products on the surface of the skin and in the hair follicle and pores

* Pickling is the adjustment of the pH of the skin or hide to the level desired for tanning or hide preservation.

5.1.1.3 Tanning

By definition tanning is "that or the processes which convert hide or skin into leather".

The lack of an adequate definition probably depends on the fact that tanning is a very extensive conception. The different chemical and physical effects of a tanning process are meant to give different properties to the leather e.g. a soft or a hard leather.

The idea behind tanning is to preserve the fiber structure and make it durable, primarily by removing fat tissues etc. from the structure.

The methods are mainly:

I Vegetable tanning
  - Condensed tannins
  - Hydrolyzable tannins

II Mineral tanning
- Chrome tanning
- Zirconium tanning
- Iron tanning

III Oil tanning

IV Combination tanning
- Semi-chrome tanning

V Other methods
- Synthetic tannins
- Aldehyde tanning

Vegetable tannins come from a wide variety of plants, and may be found in wood, leaves, bark etc. The tannin from a particular plant consists of many substances. Furthermore the tannin extracts are often mixed with one another in order to achieve a desirable result. This is often based on empirical skill. Normal vegetable tanning by the traditional method is in a rocker system, where the hides are hung on racks in pits containing tanning materials. The hides are gently rocked in the tanning solutions for approximately three weeks, in which time the leather is placed in solutions of gradually increased strength. What tannins have been used is reflected in the colour and quality of the leather. The colour may vary from yellow brown to dark red and the texture from soft and loose to hard and stiff.

Chrome tanning is the mineral process which is used today. The recipes vary here as well causing differences in leather quality. The reason for using chrome, (higher chemical cost), is that the process time is substantially shortened. After the tanning process has been completed the leather is washed in order to wash out metal salts, and neutralized by addition of e.g. sodium bicarbonate, in order to remove oxygen bound to proteins in the leather.

Combinations of the two methods described above may be used, e.g. chrome tanning after vegetable tanning or vice verse.

The final processing after tanning may consist of dyeing and different kinds of mechanical machining such as lapping, grinding to the right shape or surface polishing.

5.1.1.4 Design of Seals

Discs are punched from the leather. These are pressed wet into the desired shape. Stiff leather as impregnated chrome leather requires hot pressing. The dry seal is cut to its right height, given a centre hole and a beveled upper border.

Impregnation with wax or oil is required in order to minimize the water uptake of the seal, i.e. minimize the swelling. To make possible penetration of the impregnating substance, the seals are put in a hot wax mixture so that the remaining water can be reduced.

A number of different substance are used for impregnation;

I Animal fats
  - from land-living animals
    (grease, woolfat, bee's wax)
  - from sea living animals
    (cod liver oil, herring oil, whale oil)

II Vegetable fats
  (castor oil, linseed oil, carnuba wax, Japan wax)

III Mineral fats
  - refined mineral oils (paraffin wax)
  - ceresine

An effective impregnation is for example a mixture of linseed oil with paraffin and carnuba wax. The oil makes the penetration easier. Carnuba wax has a relatively high melting point (83-86°C) and gives resistance to the impregnation.

5.1.1.5 Quality Consistency

The quality of a leather seal depends on the skills and experience of the leather professional. A lot of things will affect the final quality of the leather below some of these are listed;

* what animal is used, what quality.
* what piece of the hide is used.
* what methods and recipes are used.
* process time for the different steps in leather preparation.

These things put together mean that the quality of e.g. vegetable tanned seal will vary from make to make and even within the same make and that there are no ways of specifying or controlling the quality. Comparative field and endurance tests are of course possible in order to sort out qualities or makes which are not suitable.

5.1.2 Rubber

5.1.2.1 Structure of Rubbers

Rubber molecules are arranged in long chain like configurations, which are in constant thermally induced motion. The substance could be looked upon as a snarled mass of fishing line with twisted and intertwined elements.

At a certain temperature, there is one, statistically, most probable spatial distance between any two points on a given chain. When a force changes this distance, the thermal movement of the system sets up a force to restore the original distance. This action accounts for the elasticity.

Within the elastic solid the segments are relatively free to move with respect to one another, but only to the extent that they encounter mechanical entanglement or upon vulcanization are "hooked" together at chemically reactive sites on the chains.

The response pattern of a rubber material can be altered by adding e.g, a filler substance or a lubricant. In the first case the result will be a stiffer rubber compound and in the second case a softer one. Further on, the smaller and fewer the chemical attachments along the chains are, the greater is the elasticity.

5.1.2.2 Use for Rubber for Design

When selecting a rubber for an application a number of things must be considered e.g.:

- mechanical or physical service requirements
- operating environment
- a reasonable life cycle
- possibility to manufacture the part
- cost

As with most selections the choice is often a compromise. Furthermore, within each rubber family a wide range of available properties exist. These are made possible by compounding; i.e. incorporating additives which improve certain properties.

The following standards are often used when identifying and selecting a certain rubber quality.

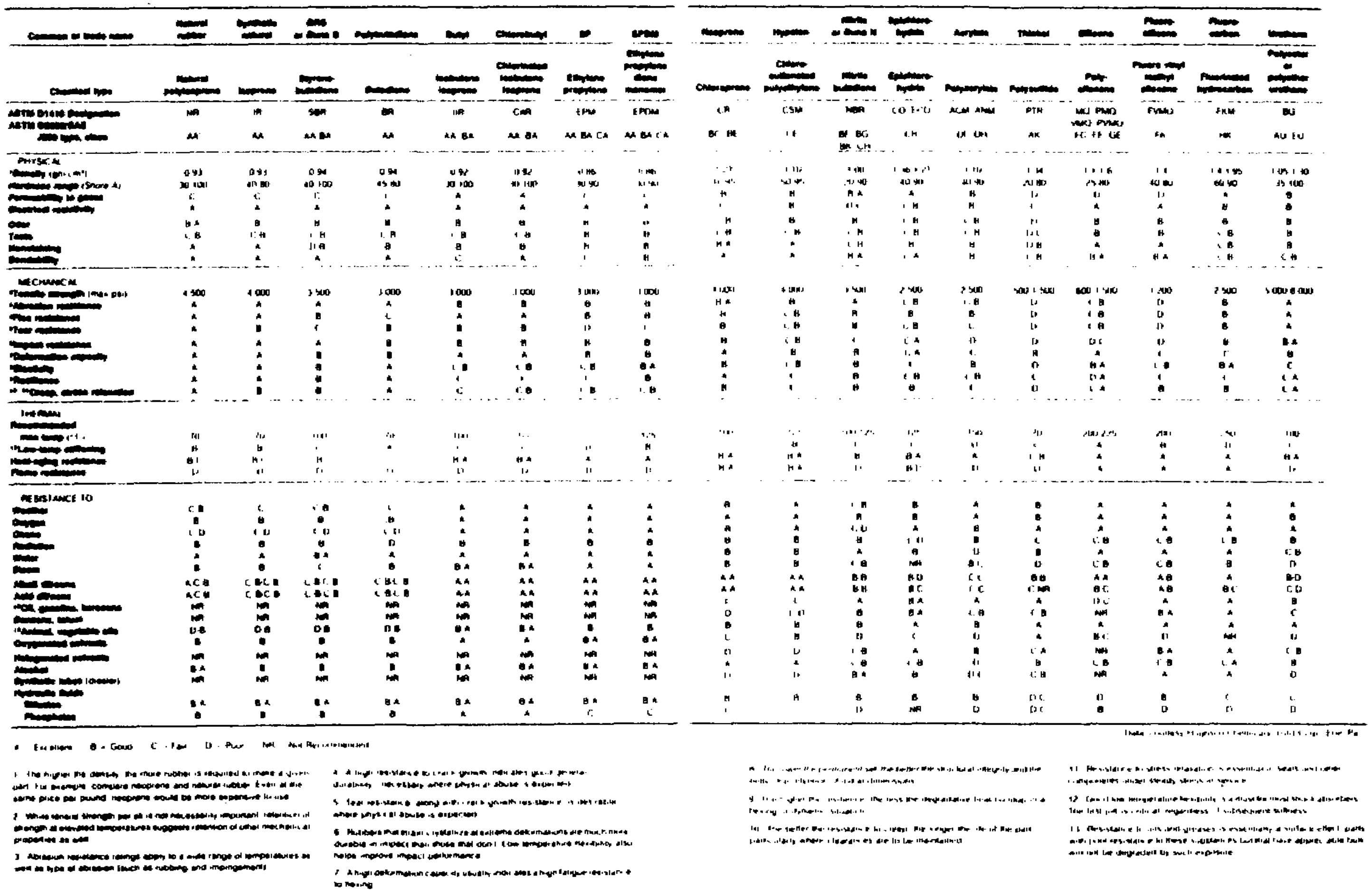
ASTM D1418:	Rubber and Rubber Lattices-Nomenclature. This standard describes all available rubbers in terms of their chemical compositions.
ASTM D1566:	Standard Definitions of Terms Relating to Rubber. This reference helps to ensure unambiguous communication among producers, molders, and designers of rubber parts.
ASTM D2000:	Standard Classification System for Rubber Parts in Automotive Applications. This standard, despite its title, is not limited to automotive parts, and is probably the most important document of all.

5.1.2.3 Different Rubber Materials

In table 5.1 different rubber materials are presented. However, it must be noted that some properties are possible to change by compounding. As a broad classification the following three types can be distinguished.

- Natural Rubber
- Synthetic Rubber
- Oil-Resistant Rubber

Table 5.1 Selection and service guide for rubbers (Larsen 1985).



A = Excellent B = Good C = Fair D = Poor NR = Not Recommended

For hydraulic applications, where oil is used, only oil-resistant rubbers can be employed. Among these rubbers especially nitrile, neoprene and urethane have come to extensive use. It is however not clear that these materials are superior as handpump seals. For example in table 5.1 it can be seen that urethane is probably not a very good material for this application and that natural rubber should perform well.

5.1.2.4 Design/Production

Rubber is shaped plastically at a temperature of 70 to 120°C. The final properties are achieved by vulcanizing the material at a temperature of 150-200°C. Rubber can be vulcanized together with a number of materials e.g. textiles, metals, ceramics and plastics.

Rubber seals can be produced in almost any shape, the optimum design will to some extent be discussed in chapter 5.5.

5.1.2.5 Quality Consistency

As rubber can be specified according to standards e.g. ASTM and this specified quality can be controlled, it seems possible to produce seals of a uniform quality. However, what rubber material (specifications) and what shape is required can only be determined by comparative field and/or endurance tests.

5.2 Correlation of Laboratory Results to Field Results

So far laboratory tests have attempted to simulate field conditions as far as possible. This will lead to quite complicated test designs and long test periods and as there are numerous seal materials and designs very few can actually be tested. With a more simple, less expensive and more rapid laboratory test, which could be used in the field rather than in a test institute, the number of seals tested could be increased and a quality control of different seal deliveries could be implemented. This test design however must be correlated to field experience. In the figure below the way to do this is shown. Selected seal materials, preferrably ones which have already been tested both in the field and in the laboratory, are used for correlating laboratory and field results. Different test designs, e.g simple wear tests, are tested with the same materials and correlated to the same results. New materials are then used for verifying the relevance of the design i.e these materials must be tested either in the field or in the more elaborate test design as well.

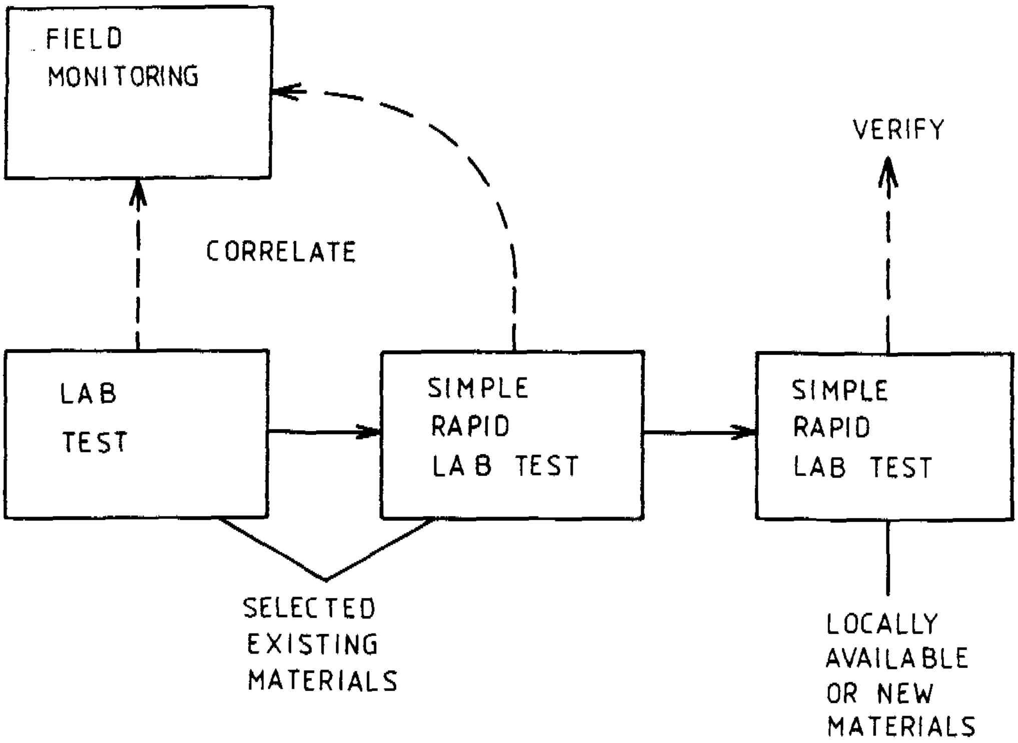


Figure 5.3 Correlation and use of simplified test design.

5.3 Single or Multiple Seals

There have been discussions whether one or two seals should be used. It has been suggested that the friction between the cylinder and the seal would be very much higher it two seals were used instead of one. Furthermore it has been said that the use of two seals does not increase the operation time of the system.

In order to measure the friction due to the seals and to see if a simplified test apparatus for endurance testing of seals could be used a new test rig was built.

5.3.1 The Test rig

As the seal friction is very small compared to the other forces in a complete handpump system it was soon realized that it was not possible to measure it in the old test rig. When the new test rig was built this was taken into consideration and partly dictated the design features. In figure 5.4 the principle of the design can be seen.

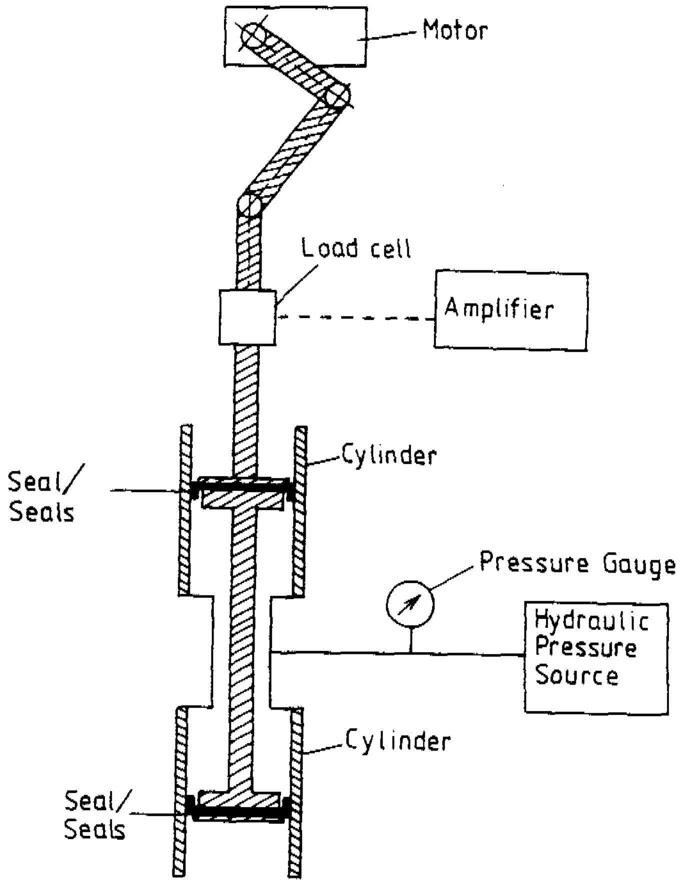


Figure 5.4 The new test rig

The basic idea is that the water should only be displaced and thus the work needed for actually pumping the water is minimized. Although all dynamic effects have not been overcome, the force recorded is mainly caused by the seals. An even better alternative, if only the friction is to be determined, is to move the cylinder instead of the piston, see figure 5.5.

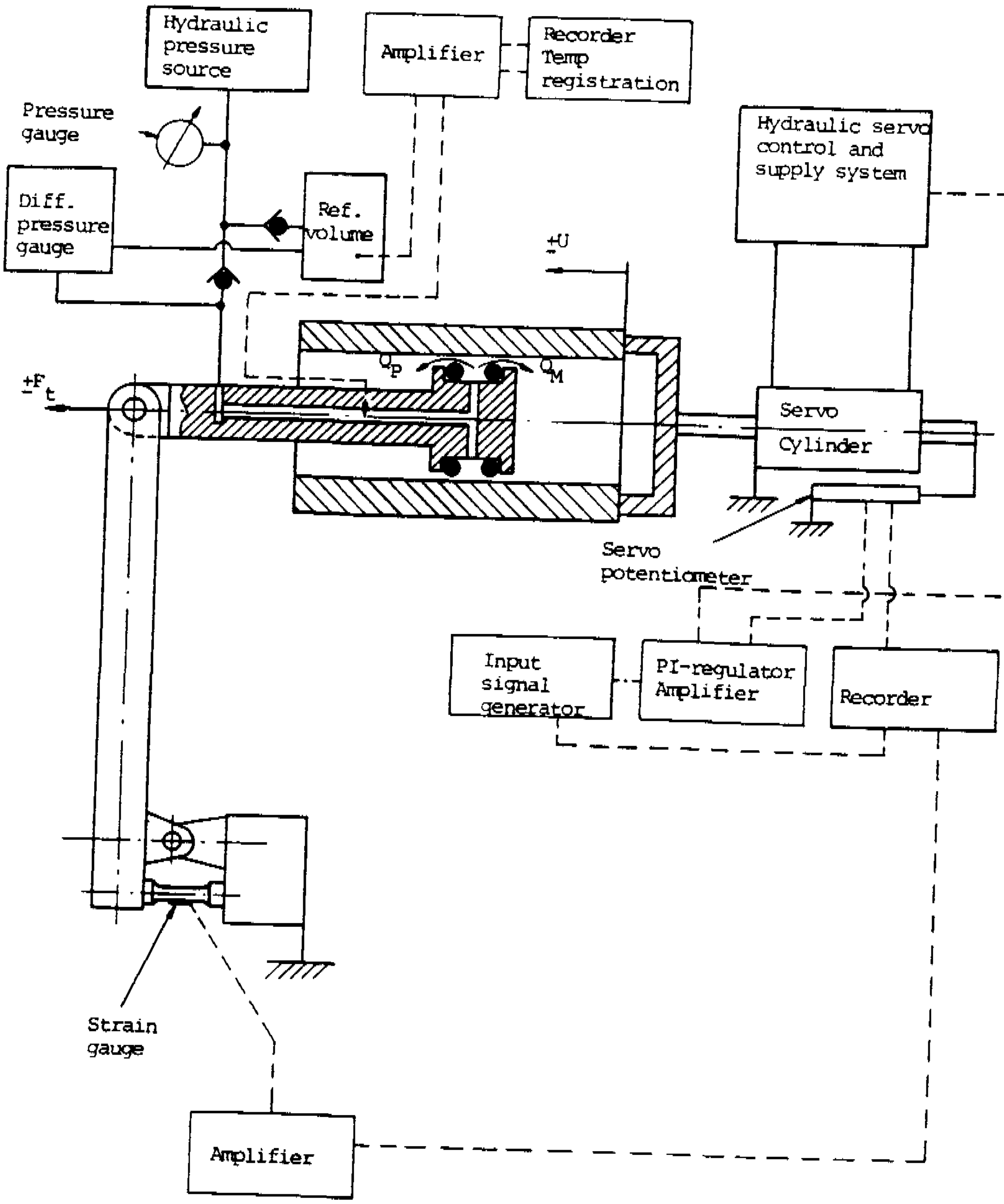


Figure 5.5 Test apparatus for determining seal friction and leakage flow (Johannesson, 1980)

The seals which are turned towards one another will from a theoretical point of view have different functions one will work as a motor seal and the other one as a pump seal. This will however not be further discussed as the theory behind the sealing function is quite complicated and beyond the scope of this work. The friction caused by the seals will be affected by a number of factors such as; seal material, seal shape, seal size, cylinder material, bore finish pumped media, pressure, piston speed etc. In this application the stroke length was 128 mm and the pumping speed was 52,7 strokes/minute which yields an average piston speed of 0,2 m/s. The pressure could be varied between 0 and 4 bar.

The test rig has not yet been used for endurance testing.

5.3.2 Friction Forces

A small test series was made in the test rig in order to measure the seal friction for different seals and different number of seals. Before measuring the friction, the seals were let to swell for six days and run for about 2000 strokes, this in order to accustom the seals to the environment. As stick slip conditions can be expected, i.e. the pressure over the seal will vary according to the figure below if the piston speed is kept constant, and the piston speed varies in time only the maximum friction forces were recorded.

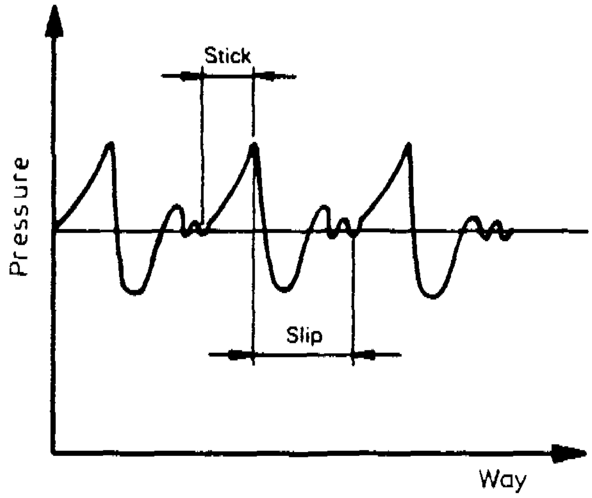


Figure 5.6 Schematic figure of stick-slip variation.

The results from the measurements are shown in figure 5.7 and 5.8. Note that the values given represent 2 pistons i.e. to get the friction for one piston the values should be divided by 2.

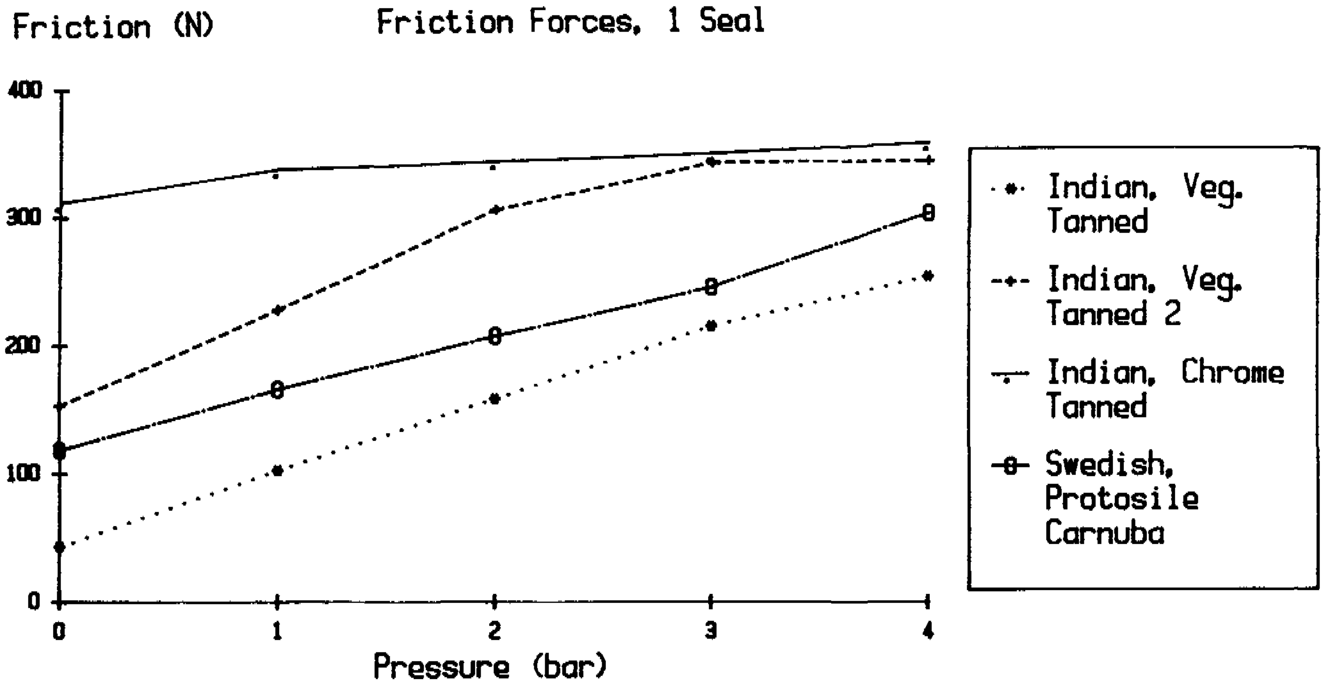


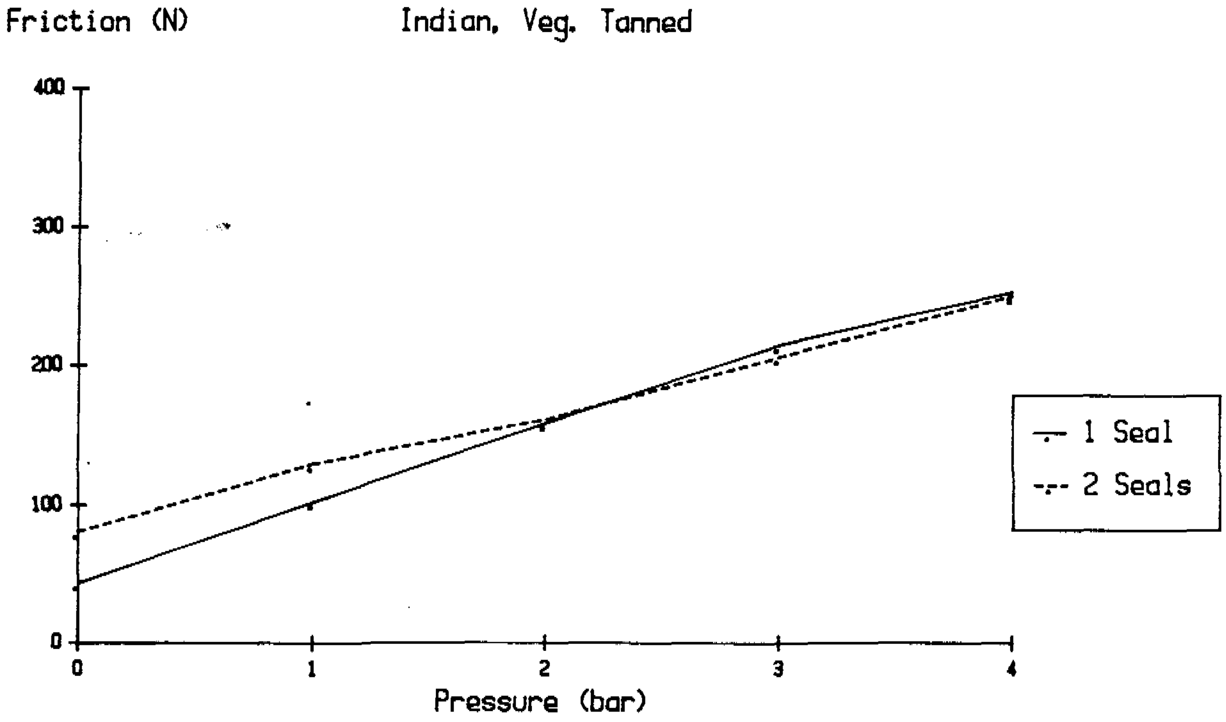
Figure 5.7 Friction values for 2 pistons, average velocity v = 0,2 m/s, brass cylinders.

Although the measurements are quite rough it is possible to get a broad view of how the friction varies for different leather seals.

The rubber seals were found to leak at 0 bar which made it impossible to test these in the same manner as with the leather seals. The seals need not to be perfectly tight but the leakage flow must of course be kept within reasonable levels. During the endurance test, no difference in flow between pumps with leather and rubber seals could be noticed. The friction for rubber seals was at 0 bar within the range 20-50 N.

In figure 5.7, where each piston has one seal, it can be seen that the difference in friction between different seals is greater at low pressures than at higher ones. This has probably to do with the initial friction obtained at installation. For example an oversized seal is likely to have a larger contact surface with the cylinder than an undersized one at low pressures thus the friction will be greater for the oversized one. On the other hand the undersized seal is probably easier to deform than the oversized one, as it is likely that the space between the seal and the cylinder is larger here, i.e. if the pressure is increased, the contact surface for the undersized seal, will probably increase more than for the oversized one and hence the friction.

In the case where two seals are used it is probably very important to have a low friction at a low pressure, as the total friction will consist of that from both seals. For example consider a case where only the upper seal is working the friction contribution from the lower seal will be that at 0 bar, i.e. if the initial friction at 0 bar is high the contribution might be substantial. In figure 5.8 a comparison between two seals and one seal is shown.



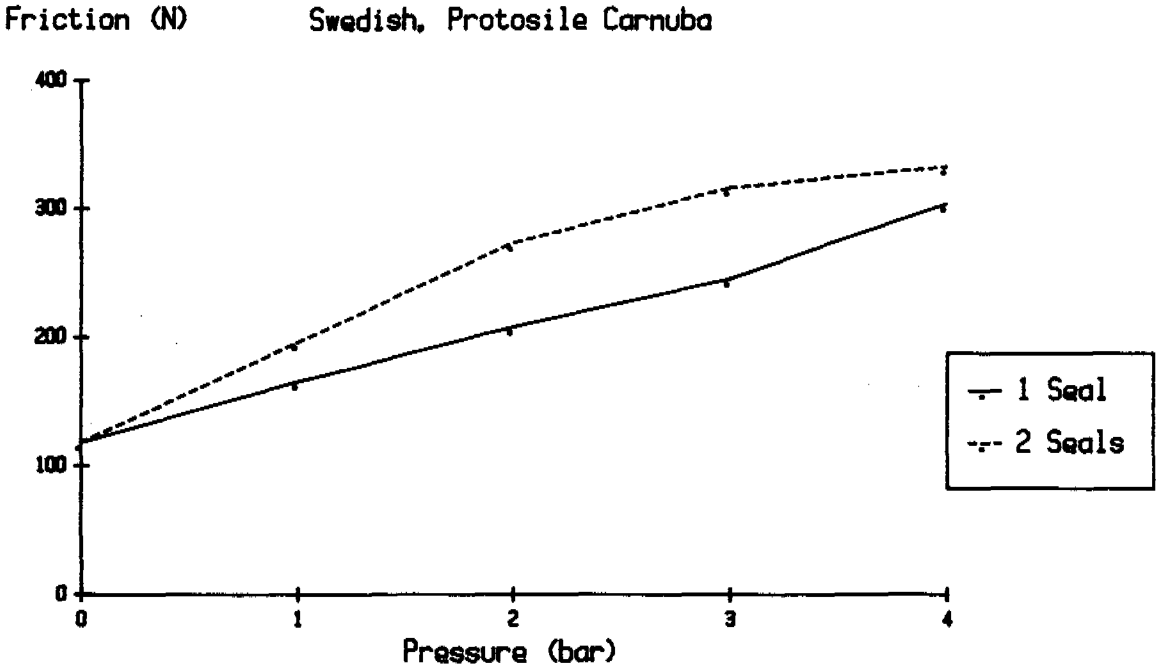


Figure 5.8 Comparison of friction for one and two seals.
2 pistons v=0,2 m/s.

Although the figures do not fully agree with the discussion above the following can be seen. The friction difference between the two seal case and the one seal case is bigger for the make with the highest 0 bar friction. There are of course uncertainties when measuring the friction which might have affected the result e.g.

- Dynamic effects are present, these will overestimate the friction in the one seal case in comparison to the two the seal case
- The seals are of a varying quality, i.e. swelling, size etc may vary

Another case where the friction at low pressures is important is when a pump with a gravitational backstroke is used. In many cases the piston has become stuck in the cylinder because of oversized seals.

For practical reasons the following can be said;

- if the seals are well chosen, low friction at a low pressure, the friction contribution from a second seal is negligible.
- the maximum friction for two well chosen leather seals could be expected to be within the range 50-150 N in brass cylinders at normal depths, 10-30 metres.

5.3.3 Wear

It has been concluded in the laboratory tests, where two seals have been used that it is not possible to predict which of the seals, if one, is to be mostly worn.

This supports the idea that two seals will yield a longer operation time than one will. As a reason for this statement the following can be said;

- if one of the seals is more rapidly worn than the other one, because of uneven quality, eccentricity etc, the remaining one will secure the function of the pump and thus the operation time is increased.

- it both seals are equally worn, it could be assumed that both of them are working i.e. the pressure on each seal is less than it would have been if only one was working. This will lead to a reduction in friction and wear on each seal and thus the operation time in increased.

5.4 System Approach

When selecting a seal, certain properties are demanded, such as long service life, low friction, resistance to the environment, etc. There is of course a relation between these properties. The properties are mainly affected by the following factors:

- The seal
  - Type
  - Piston design
  - Material
  - Manufacturing quality
- The pressure
  - Level
  - Variation
  - Number of cycles
- The Media (Water)
  - Content of particles
  - Chemical quality
- The Surface
  - Surface Roughness
  - Character
  - Material

In the following a brief discussion concerning these factors is made.

5.4.1 The Seal

The most common system today is the one where leather seals are used in conjunction with a brass cylinder, see figure 5.9

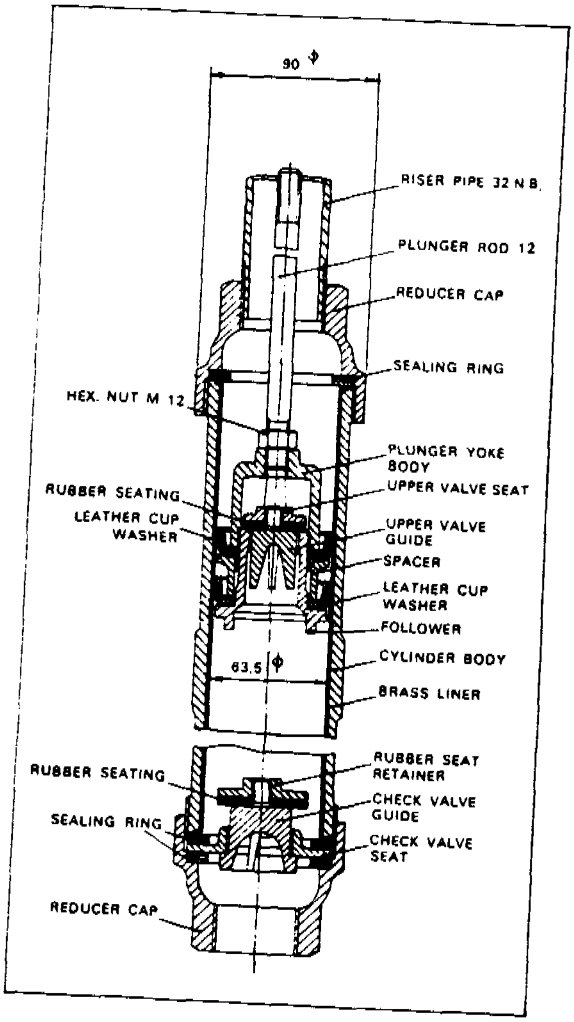


Figure 5.9 India MK II below ground assembly.

The seals have to be made in a cup shape in order to work. This of course affects the design of the piston. As can be seen in the figure the seals are kept in place by means of the yoke. Apart from the sealing function the seals have a steering function this to keep the piston somewhat in alignment and avoid scoring of the cylinder by e.g. the follower. The follower and the spacer function as support for the seal above but as the piston is always a bit tilted a play is needed between them and the cylinder this in order avoid scoring. If the play is too big the seal will be pressed into this space and be subject to unnecessary strain and stress which might lead to the collapse of the seal. In cases where the seal is very soft this can be observed as the seal is mostly worn along its base, see figure 3.6. In one case the seal was even torn apart at this point.

Another problem with soft seals is that the steering function is partly lost, i.e. they are easily deformed, thus allowing for greater disalignments and a higher risk of extrusion problems.

As a whole the piston may be said to be more or less optimized with concern to leather seals.

If rubber is used instead of leather, the properties of rubber must be considered when designing both the seal and the piston. Rubber seals can be made in a great variety of materials and in almost any shape and it is therefore impossible to say what material and what shape is the optimum for a handpump application. For hydraulic situations, high pressure (up to 400 bar) and oil, rubber is a well known material and especially nitrile rubber, polyurethane and neoprene are extensively used as they are resistant to oil. A high pressure affects the design of the seal, a cup seal would probably not work very well in a hydraulic application. For a handpump this shape is perhaps the most interesting shape since most pistons are made for a seal of this design.

There are however a number of difficulties to overcome when actually designing it. When testing nitrile rubber seals, made in the cup seal shape, 70° shore A, without any reinforcement, it was experienced that they were quite easily torn apart or displaced this depending on how hard they had been fastened. In order to overcome this a steel ring was introduced along the base of the seal, see figure 5.10.

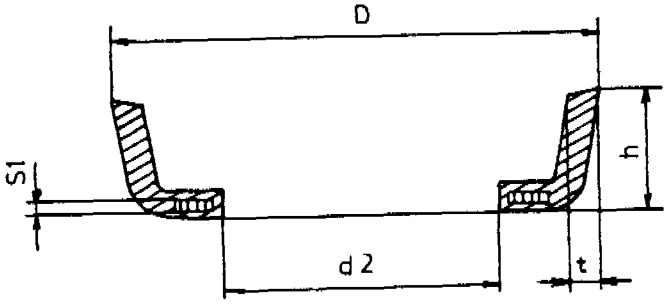


Figure 5.10 Nitrile rubber seal with steel ring.

This reinforcement had the effect that the seals were torn apart along the ring. These collapses were probably due to extrusion in conjunction within strength problems. In order to eliminate problems of this kind a textile cord could be used as a base, see figure 5.11.

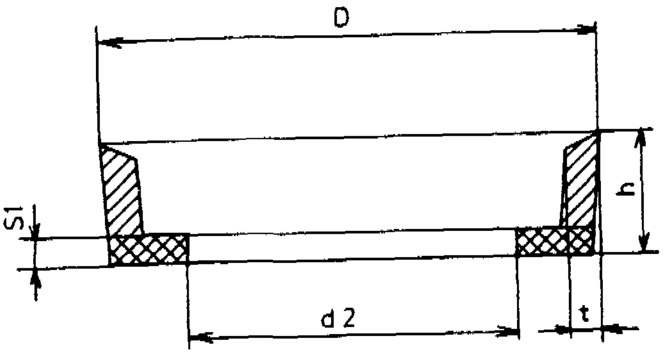
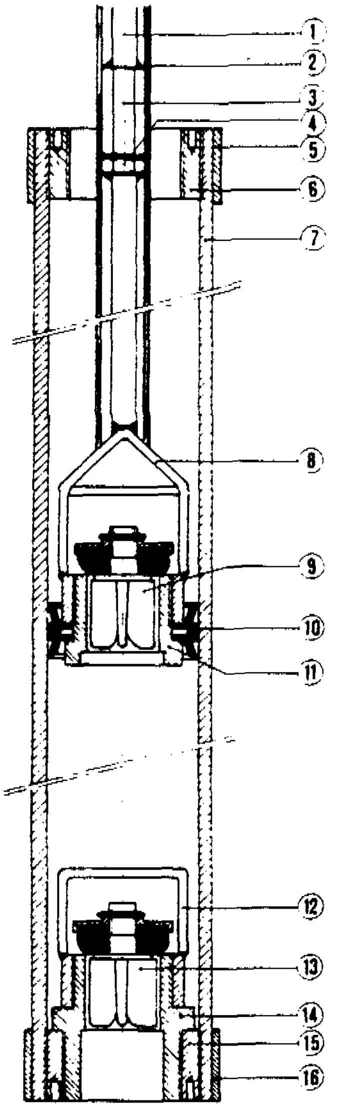


Figure 5.11 Neoprene seal with textile cord.

Another way could be to increase the hardness as a means of preventing extrusion problems, in analogy with leather seals. The seal in figure 5.11 is made of neoprene, 80° shore A, and worked without problems in the laboratory.

From the above discussion it seems probable that a rubber seal can be made in the same shape as a leather seal. This means that rubber and leather could be used interchangeably for one another.

Another way of solving the seal problem is to use one which is designed to work without any support from a piston, i.e. the seal has a steering, supporting and sealing function. In figure 5.12 this is shown.



NO	DESCRIPTION
1	pump rod (Ø 10 mm stainless steel)
2	PE tube (Ø 25/20 mm)
3	hexagonal nut (M10, stainless steel)
4	counter nut (M10, stainless steel)
5	reinforcing band (stainless steel for deepwell cylinders only)
6	plug (PVC)
7	cylinder wall (thick-walled PVC, see previous page for dimensions)
8	valve stop plunger body (stainless steel)
9	poppet valve assembly (rubber brass)
10	cup seal with double-acting piston sleeve
11	piston valve body (nylon)
12	valve stop (stainless steel)
13	poppet valve assembly (identical to that in piston)
14	foot valve body (nylon)
15	plug (PVC, identical to plug in top of cylinder)
16	reinforcing band (stainless steel, identical to that around top of cylinder)

Figure 5.12 Below ground assembly of pump.

This seal, neoprene 90° Shore A, worked very well in the laboratory. The lower part of the seal which is turned upside down is sometimes said to work as a washer in the sense that particles suspended in the water are kept from getting embedded in the seal and thus scoring the cylinder. In the laboratory test this could not be seen, the cylinder with this seal was as worn as any other one. Although no effect of this could be noticed it might have a steering effect which might improve the result for this kind of seal. Still it would probably have been better if this part had been turned the other way around.

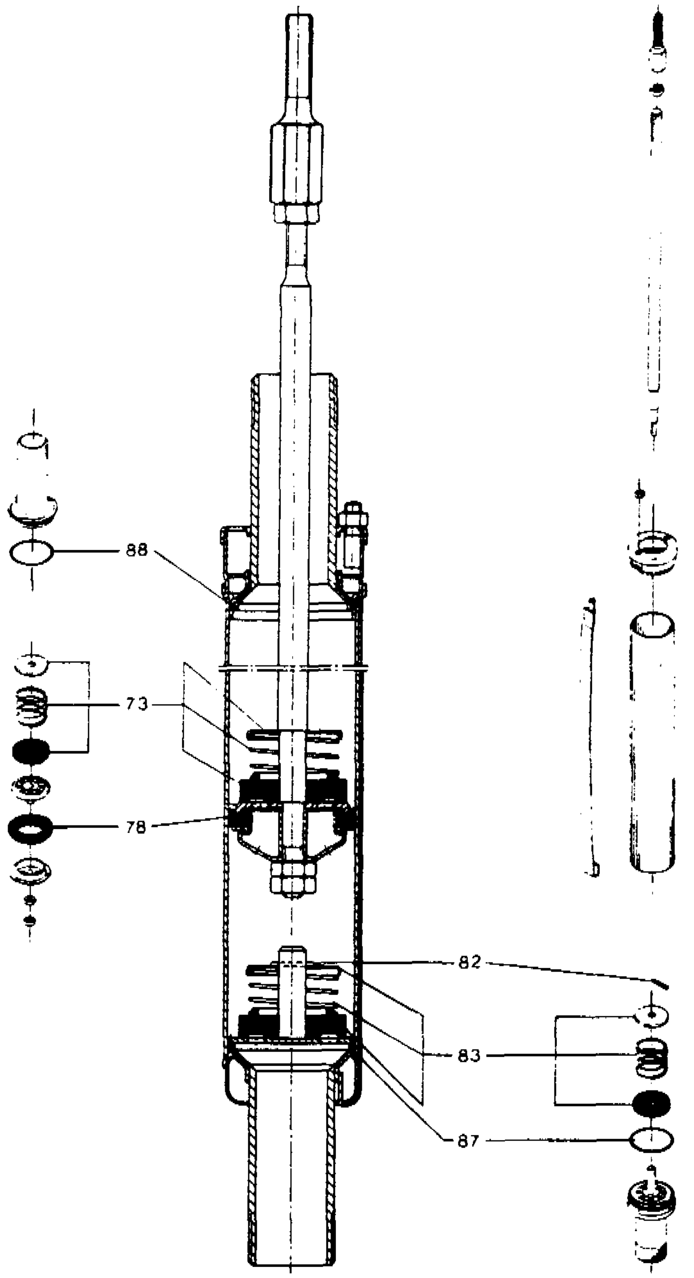


Figure 5.13 Below ground assembly with natural rubber seal.

In figure 5.13 another piston and seal design is shown. The seal material is natural rubber, 60° shore A, and is made in a u-shape, well known from hydraulic applications. Natural rubber is a very interesting seal material as long as no "oil" is present. In the laboratory tests this design did not work very well. Mainly because of a too small play between the follower and the cylinder wall. The follower scored the wall and a sharp edge was formed here which cut into the seal and hence destroyed it. If the play had been made bigger there might have been problems of extrusion since the seal is so soft.

Some kind of reinforcement might be needed just like the seal shown in chapter 3.3, or in the figure below, which worked very well in the laboratory test. On the whole a seal of this design requires a different piston design than the one used for cup seals. In the figure below some examples are shown how to construct a piston with this kind of seal. Notice the figure in the middle where a steering ring of PTFE has been incorporated, this in order to prevent the piston from scoring the cylinder wall and give guidance to the piston.

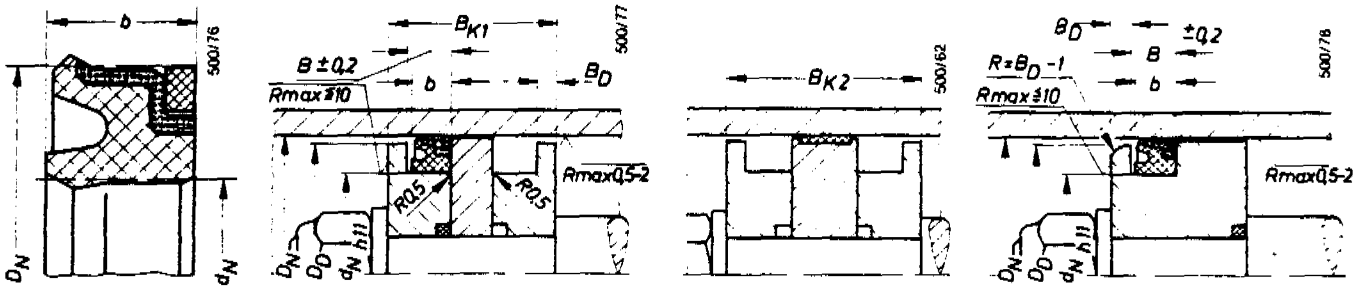


Figure 5.14 Piston designs with u-shaped seal.

5.4.2 The Media and the Surface

As the water will contain a lot of suspended particles the cylinder wall will be scored shortly after the installation, this irrespectively of what material is used. The seals are said to be relatively insensitive to particles but as these get embedded in the seal the wall will be scored as the piston is moved. This is supposed to mainly affect the leakage flow, but of course a badly scored cylinder will increase the wear of the seals as well.

The scoring is more of a macro scale effect than micro scale one and soft materials like PVC will be more affected by it than stainless steel. On the other hand a soft cylinder material seems to cause less seal wear, see figure 3.10. For the whole system it is of the utmost importance that the particles are kept from scoring the cylinder wall. The particle separator, see figure 5.15 has been designed for this purpose.

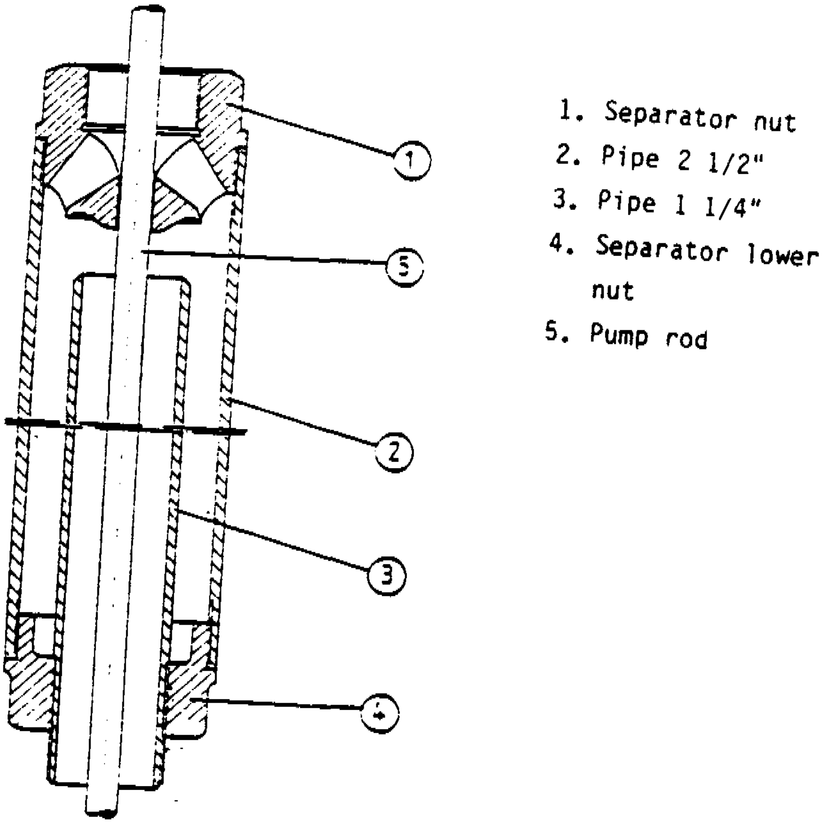


Figure 5.15 Particle separator (Sholapur Well Service).

The separator when placed directly above the cylinder, will protect the cylinder assembly not only from sand sucked in with the water but from metal particles resulting from constant abrasion of the moving parts in the above ground construction and contact rod-rising main.

The volume of the separator, length of the tube, can be selected to fit the expected particle sedimentation. If the separator gets full before it is emptied, the pump will work as if no separator was present. The field study in Coimbatore proved the effect of the separator.

The separator is a more reliable alternative than an intake screen, since the screen has to have a rather fine mesh to be effective, in which case it is easily clogged and thereby hindering operation.

To prevent larger particles from entering the pump, a 1-2 m long intake pipe can be used. The pipe should have the same diameter as the cylinder and be placed directly under it. Tests in Coimbatore, however, have not indicated any measurable effect on seal wear because of the intake pipe.

Another thing which is often neglected is the cleansing of the cylinder when the seals are changed. After a very short while a thin layer will form on the cylinder where the piston is not run and as it is not probable that the piston will be in the very same position as it was before the seals were changed this layer must be removed before the pump is put into operation again, in order not to cause unnecessary seal wear.

5.5 What and How to Choose

It has been shown here and elsewhere the importance of treating the whole below ground assembly as an entity. In many cases the seals break down for other reasons than wear. In these cases the material and or the design should be changed. However seal wear is inevitable. This of course does not exclude that new materials and new designs should be tested in search for the optimum handpump design.

Leather is the far most common material when seals are concerned. In order to avoid problems with pistons getting stuck in the cylinder the following dimensions should be used when ordering the seals for a 2.5" cylinder. Only the best parts of the hide should be used e.g. for cattle, butt or bend.

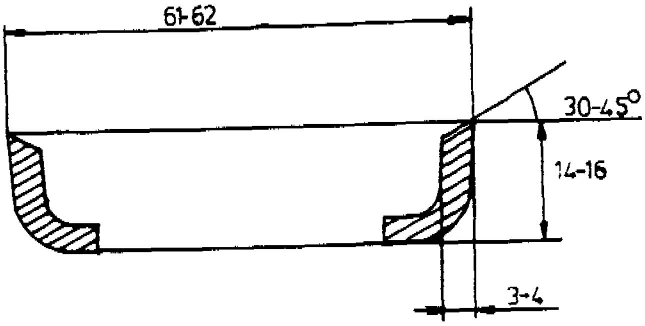


Figure 5.16 Recommended leather seal dimensions for a 2.5" cylinder.

In some cases it might be useful to submerge the seals and the cylinder into water and see what the swelling will be like. The seals should be submerged for at least six days. If the seal diameter, when taken out of the cylinder, exceeds the inner cylinder diameter with more than 2-3 mm, or the piston needs a load larger than about 10 kg in order to sink in the cylinder the seal is probably of a poor quality and should not be used.

The seal should not be to soft as this will lead to extrusion and unnecessary wear. This has to be observed on worn out seals if it is worn out along its base or damaged here a stiffer quality should be chosen. In this context it is important to note that a stiff seal will not yield full capacity until after some days, it needs to swell before an appropriate function is achieved. A swelling test might be useful when determining this.

Vegetable tanned seals should be used as they have proved equal to chrome tanned ones. Chrome tanning as a process is more harmful for man and environment than vegetable tanning.

The flesh side should be used as the wear side. This statement has not been proved but it seems reasonable that the stability is prolonged if the grain side is left unharmed see chapter 3.3.

Wax with a high melting point, e.g. carnuba wax, should be used in the impregnation mixture.

Leather seal quality will always vary but on the other hand well chosen leather seals may by superior to any other alternative as especially the availability is high. In order to determine what seal is best testing is required.

Rubber materials have aroused interest as they could be more accurately specified than leather seals, i.e. a certain material quality, shape, etc can determined. So far very few rubber seals have been tested and it is therefore not possible to specify this seal at this point. However it seems possible to make a rubber seal which will perform as well as the best leather seal.

A number of rubber qualities will be suitable, as shown in table 5.1. Furthermore, several designs of rubber seals will serve the purpose. One which is particularly interesting is the one which resembles the leather cup seal, as this would allow for using either leather or rubber seals depending on what is available. When designed in this way the seal should probably be relatively hard, 80° Shore A, and have a reinforced base with a textile cord, as in figure 5.11. As rubber seals have little swelling the dimensions of the seal can be optimized with concern to the leakage flow and the friction. As for the u-shape seal the same hardness and reinforcement is probably needed. Still many other rubber seals remain to be evaluated.

6. Conclusions

The Test Design

- The test period, 4000 hours, is sufficient to sort out the seals which are not suitable for the purpose, but far to short for determining the operation time of high quality seals.
- Addition of sand in the water increases the wear, but to what extent is not possible to tell from this test. Here the effect could mainly be seen as increased scoring of the cylinder wall.
- Increased pressure from 3 to 7 bar did not increase the wear substantially during the 4000 hours, but seal deficiencies (design or material) can more rapidly be detected.
- Since no standard procedure exists for testing piston seals, the test rig should as much as possible simulate field conditions.
- Future work is needed, to correlate available data from laboratory and field studies. This will enable simplified, less expensive and more rapid test methods.
- A simple test procedure is important to develop, as seal quality control and assessment of alternatives always will be required.

The Piston Seal

- The quality of leather seals is heavily dependant on quality of the raw material, i.e. origin of the hide, parts of the hide used, pre-treatment before tanning etc.
- The skills and experience of the personnel is probably more important than the actual tanning process and recipes.
- Vegetable tanning is preferred to chrome tanning, since no difference could be seen in the tests between the two and since the chrome process is more harmful to man and environment.
- The leather cup should be made with the flesh side outwards, in order to have the more dense parts of the leather left to stabilize as long as possible.
- To avoid extrusion the leather should be rather stiff.
- Using a stiff leather, the swelling might cause the piston to get stuck in the cylinder. To prevent this dimensions according to figure 5.14 are recommended.
- A simple swelling test, with the cup seals on the piston submerged in water in the cylinder for about 6 days, is helpful when determening the right seal diameter.
- Leather seals should be impregnated carefully, with a mixture including a hard wax, like carnuba.

* Of available synthetic materials, rubber seems to be the most suitable material for piston seals.

* Types of rubber likely to perform well, include nitrile, neoprene and natural rubber.

* The shape of the rubber seal should preferrably be similar to leather cups, in order to have flexibility to choose between leather or rubber.

* Rubber seals with a u-shape have also proved to perform very well.

* The rubber hardness should be in the range 75-80° shore A.

* The base of the rubber cup seal needs to be reinforced. So far textile cord has given the best result.

* The accuracy of the diameter is also important for rubber seals. Too large a diameter will result in an unnecessary high friction. Too small a diameter will result in an unacceptable leakage. An optimum between these two must be sought.

* Multiple seals are likely to yield a longer operation time than a single seal system.

* The increase in friction from two seals instead of one is negliible in deep well pumps.

* Two seals instead of one will probably help to improve the alignment and thus reducing problems with scored cylinder walls and related problems.

The Cylinder Assembly

* The cylinder assembly must be seen as an entity. The selection of seal material is dependant on the operation conditions for the seal.

* The character of the cylinder wall is of the outmost importance when seal wear is concerned. Micro scale surface roughness is likely to be more defective to the seals than macro scale vertical scoring.

* Soft cylinder materials like plastics, will spare the seals, but are at the same time more rapidly scored.

* For metal cylinders, brass is a good alternative. Stainless steel cylinders, being a harder material, have to be well polished.

* When replacing seals, cleansing of the cylinder is necessary. The piston will often not come to operate exactly in the same section of the cylinder as before. Scaling and oxidation on unused parts of the cylinder will rapidly "eat" the new seals.

- Particles in the water, sand from the well and metal particles from abrasion of the pump, should be avoided. Primarily these will affect the macro structure of the cylinder wall and thus indirectly increase the seal wear.

- Intake screens will have to have a rather fine mesh to be effective, thereby at the same time creating a risk for clogging.

- A particle separator above the cylinder is to be preferred as also metal particles will be separated, which is not the case with an intake screen.

- A particle separator like the one in figure 5.15 can be installed in all types of reciprocating pumps. If the sand pocket is full, the pump will only behave as if no separator was there.

REFERENCES

Arlosoroff et al. (1985) Handpumps Testing and Development: Progress Report on Field and Laboratory Testing. Rural Water Supply Handpumps Project. UNDP Project Management Report No 4. World Bank Techn. Paper No 29.

CATR (1982) Laboratory Testing, Field Trials and Technological Development. Rural Water Supply Handpumps Project, UNDP Project Management Report No. 1, GLO 79/010, INT/81/026.

CATR (1983a) Handpump Test Procedures

CATR (1983b) Laboratory Evaluation of Handoperated - Water Pumps for Use in Developing Countries. Rural Water Supply Handpump Project, UNDP Project Management Report No 2, World Bank Techn. Paper No 6.

CATR (1984) Laboratory Testing of Handpumps for Developing Countries: Final Technical Report. UNDP Project Management Report No 3, World Bank Techn Paper No 19.

CATR (1986a) Handpumps Laboratory Test Results. Rural Water Supply Handpumps Project. Applied Research and Technology (WUDAT) - Note No 2.

CATR (1986b) Plastics in Below Ground Components of Hand Pumps.

CROWN Agents Services Ltd. (1986-1987) Quartely Report no 12 and 13. Field Testing of Deepwell Handpumps C.A. Ref. TXH/TXP/INDIA WB 3/95422/1.

Fannon Jr, R.D. and Frink D.W. (1970) Final Report on The Continued Development and Field Evaluation of the AID Hand-Operated Water Pump. Batelle Memorial Institute, Columbus Laboratories Contract No AID/csd-2174.

Fannon Jr, R.D. and Frink D.W. (1975) Field Research and Testing of a Water Hand Pump for Use in Developing Countries. Batelle, Columbus Laboratories.

Frink, D.W. and Fannon Jr, R.D. (1967) The Development of a Water Pump for Underdeveloped Countries. Batelle Memorial Institute, Columbus Laboratories Contract No AID/csd-1434.

Government of Bangladesh The World Bank, UNICEF, MAWTS (1985) Report of The Workshop on the Design of the Tara Handpump. Dhaka, Bangladesh, October 13-17, 1985. Part 1- Main Report, Part 2- Drawings.

Guindo D. (1986) Rapport Final sur les Essais de Terrain au Burkina Faso. Banque Mondiale, Projet Pompes a Main INT/81/026.

Hahn, R. (1983) Handpump Testing and Development. Part 3 New Design. Dept. of Environmental Engineering, Lund University, Sweden.

Hahn, R. (1985) Rural Water Supply in Developing Countries. LUTVDG/(TVVA-1001)/1-100/(1985). Dept. of Environmental Engineering, Lund University, Sweden.

Hahn, R. and Johansson, P. (1986) Handpump Testing and Development. Part 5. The Second Year - Results of Completed and Ongoing Tests. Dept. of Environmental Engineering, Lund University, Sweden.

Hahn, R (1987) Laboratorietest av Handpumpar. Sammanfattning av tester utförda åren 1982-1986. Dept. of Environmental Engineering, Lund University, Sweden. (In Swedish).

Hofkes E.H. and Kah-Lin C. Handpumps for use in Rural Water Supply Programmes in Developing Countries. Technical Paper No 23. International Reference Centre for community Water Supply and Sanitation, The Hague, The Netherlands.

IDRC (1984) Inside the PVC Pump. IDRC Reports 1984, 13 No 3, 7-8.

IRC (1979) Handpump testing and evaluation: Report on an international working meeting held at Harpenden, Hertfordshire, England. International Reference Centre for community Water Supply and Sanitation, The Hague, The Netherlands.

IRC (1981) Handpump Catalogue, Preliminary Draft Edition, International Reference Centre for community Water Supply and Sanitation, The Hague, The Netherlands.

IRC (1982)	*Hand Pumps,* joint publisher United Nations Environment Programme and the World Health Organization, International Reference Center for Community Water Supply and Sanitation, No. 10, Technical Paper Series, The Hague, The Netherlands.
IST (1984)	*Specification for Deep-Well Hand Pumps.* Indian Standards Institution, IS:9301.
Johannesson, H. (1980)	*On the Optimization of Hydraulic Cylinder Seals.* Dept. of Machine Elements Division University of Luleå, Sweden.
Kigingi A.K (1984)	*Operation and Maintenance of Shallow Wells in Morogoro Region.* Tampere University of Technology Department of Civil Engineering. Tampere, Finland.
Larsen, P.J. (1985)	*Materials and Processes.* Third Edition. Eds. Young J.S.and Shane R.S: Chapter 11, section VII Rubber. Marcel Dekker, New York.
Malila et al (1979)	*The Development of a PVC Handpump, Phase I.* Mechanical Engineering Department Chulalongkorn University, Bangkok, Thailand.
Nimityongskul, P and Karasudhi, P (1982)	*Final Report on Water Pumping Technology (Global) - Thailand.* Asian Insititue of Technology, Bangkok, Thailand.
Nyström, M. (1985)	*Kitchen and Stove. The Selection of Technology and Design.* LCHS, Lund University, Sweden.
Potts et al. (1979)	*Final Report on the Utilization/Evaluation of an AID Hand-Operated Water Pump.* Georgia Institute of Technology. Contract No. AID/ta-C-1354.
Potts P.W. (1981)	*The Aid Hand-Operated Water Pump. A classic Example of Technology Transfer.* Georgia Institute of Technology. Contract No. AID/ta-C-1354.
Potts, P.W. and Dixit, B.S. (1984)	*Laboratory Testing of Hand-Operated Water Pumps.* WASH Field Report No. 131. Contract No. AID/DSPE-C-0080.
Prasad R. (1979)	*Handpumps: Problems and the Search for Remedies* Dept. of Civil Engineering, Indian Institute of Science, Bangalore, India.

Rogers, M. (1984) An appropriated Technology: Handpumps in Sri Lanka. IDRC Reports 1984, 13, No 3, 9-10.

Rural Water Supply Handpumps Project Team (1986) Draft Sample Bidding Documents for the Procurement of Handpumps, Rural Water Supply Handpumps Project. Applied Research and Technology (WUDAT) - Note No1.

Sharp D. and Graham M. Eds. (1982) Village Handpump Technology Research and Evaluation in Asia. IDRC-204e, International Development Research Centre, Ottawa, Canada.

Subba Rao S. and Sen Gupta J. N. Study of Hand Pump (Shallow Tube Well) For WHO/UNICEF assisted Projects and other Rural Water Supplies. Phase II, Design, Fabrication and Testing of Modified Hand Pump (SINGUR).
Part 1:
Report on Laboratory testing. Section of Public Health Engineering. All India Institute of Hygiene and Public Health, Calcutta, India.

Teknologisk Institut (1955) Garverbogen, Third Edition Ed. Aabye J.S. Teknologisk Instituts förlag. Copenhagen, Denmark (In Danish).

Thorstensen, T.C. (1969) Practical leather Technology. Reinhold, New York.

Tschannerl G. and Bryan K eds. (1985) Handpumps Testing and Development. Proceedings of a Workshopin China. UNDP Project Management Report No 5. World Bank Technical Paper No 48.

Veturlidason, S (1983) Laboratorietest av Handpumpar. Dept. of Environmental Engineering, Lund University, Sweden (in Swedish).

WHO, Regional Office for South-East Asia (1976) The Bangalore Pump. SEA/ENV. SAN./168. New Delhi, India.

Yau, G.S. (1985) Laboratory and Field Testing of Handpumps. IDRC-TS51e, International Development Research Centre, Ottawa, Canada.