NATSURV 5

WATER AND WASTE-WATER MANAGEMENT IN THE SORGHUM MALT AND BEER INDUSTRIES

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Water Research Commission

By

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FOREWORD

The need for guidelines to reduce water intake and waste-water disposal by industry is of national concern in view of South Africa's water scarcity.

To establish norms for water intake and waste-water disposal, the Water Research Commission (WRC) in collaboration with the Department of Water Affairs (DWA) contracted Binnie and Partners (now amalgamated with Steffen, Robertson and Kirsten), a firm of consulting engineers, to undertake a National Industrial Water and Waste-water Survey (NATSURV) of all classes of industry. The consultants identified 75 industrial groupings in South Africa, one of which is the sorghum malting and brewing industry. The results obtained in the survey of the sorghum malting and brewing industry form the basis of this Guide on **Water and Waste-water Management in the Sorghum Malt and Beer Industries.**

It is hoped that this Guide will be of value to the industry itself, and to other interested parties such as municipalities, administrators, researchers and consultants in the water and effluent fields.

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Dr OO Hart	-	Water Research Commission
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SUMMARY

There are 33 sorghum breweries in South Africa, the National States and Self-governing States which produce 1,1 million m^3 of beer and use 2,75 million m^3 of water annually. Thirty one per cent of the production is sold in bulk while the remainder is packaged. Sorghum maltsters produce approximately 185 400 t/a and use about 630 000 m^3/a of water.

The average specific water intake (SWI) was found to be 3,4 m^3 of water per ton of malt and 2,5 m^3 of water per m^3 of beer produced. Target SWIs have been proposed as 3,0 m^3/t for large and/or mechanized maltsters, 7 m^3/t for small maltsters (less than 300 t/month) and 2,0 m^3/m^3 for breweries.

Effluent volumes discharged for malting and brewing are about 84% and 52% of the total water intake respectively. Specific pollution loads (SPLs) were found to be 8,6 kg COD per ton of malt and 5,2 kg COD per m^3 of beer produced. Target SPL's have been proposed as 7,0 kg COD/t and 5,0 kg COD/m^3 respectively.

Extensive analyses of sorghum brewery effluent yielded the relationship:
1 OA/PV : 2,0 TOC : 11,6 COD.

Suggestions on methods of reducing the overall water consumptions and pollution loads have been outlined. Further research on all aspects covered in the guide is recommended.

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GLOSSARY

The following terms are described as they are used in the context of this guide:

ADJUNCT	A starchy cereal source (normally maize grits) upon which the amylase enzymes act.
AMYLASES	A group of enzymes which degrade starch to sugar.
BARLEY BEER	Refers to beer brewed from barley. Also called lager or malt beer.
BIRDPROOF GRAIN	Sorghum grain predatory resistant due to its high polyphenol content.
BREWERS DEGREES	The number of millitres of I M NaOH required to adjust the pH to 6,3.
BREWERS GRITS	Partially ground degermed and dehusked hard maize endosperm portions.
COLOURED TESTA	A pigmented subcoat of bird-resistant sorghum containing polyphenolic tannins.
COMMERCIAL MALTSTER	A term referring to malsters who serve the home brewing market.
CONVERTER	The vessel in which starch is converted to sugar.
COOK (n)	A brewing mixture just before or after the cooking phase.

DIASTATIC POWERS	The measures of the ability of the enzymes in the malt to convert starch to sugar.
DRY BASE	Malt or beer powders sold directly to the consumer for home brewing.
EMBRYO	A young plant within a cereal grain or seed able to sprout and reproduce the plant.
ENDOSPERM	The bulk part of a cereal grain containing reserve materials for the embryo.
ENZYME	A biochemical catalyst produced by living cells.
FAN	Free amino nitrogen required for yeast reproduction.
GELATINIZE	Thermal degradation of the adjunct to prepare for conversion.
GERMINATION	The process of sprouting the sorghum grain to change its enzymatic properties.
INDUSTRIAL MALTSTER	A mechanized indoor malting plant which normally supplies breweries.
INOCULATION	Refers to the addition of a bacterial culture to start the lactic acid fermentation process.
LACTOBACILLI	The family of bacteria producing lactic acid.

BULK BEER	Beer which is not packaged but sold in bulk to customers.
MALT	*Sorghum grain after germination and drying.*
MASHING	The process involved in the preparation of the wort.
PASTEURIZATION	The reduction of microbiological counts in a product by a thermal treatment.
PITCHING	As for **INOCULATION**.
POLYPHENOL	A substance which complexes with proteins and thus inactivates enzymes.
BEER POWDER	A cereal mixture sold in packets for dilution with water and fermentation.
PROTEOLYTIC ENZYMES	Enzymes which degrade protein.
SOLUBILIZATION	First stage of mash conversion induced by enzyme activity.
SOURING	Acidification process brought about by lactic acid bacteria.
SPECIFIC EFFLUENT VOLUME	A ratio of the effluent volume generated per unit of production.
SPECIFIC EFFLUENT LOAD	The mass of a particular pollutant in the effluent per unit of production.

SPECIFIC WATER INTAKE	The quantity of water consumed per unit of production.
SPENT GRAIN	The residue of the mash after straining.
STARCH HYDROLYSIS	A conversion of starch to sugar.
STEEPING	A preliminary soaking of the sorghum grain to rehydrate the embryo.
THERMOPHILIC BACTERIA	Bacteria capable of growth at elevated temperatures.
VENTING	An included opening in the sorghum beer package to allow the escape of carbon dioxide during fermentation.
WET BASE	Sorghum malt sold to breweries or used in the composition of powder beer.
WORT	The mixture at the end of mashing and after spent grain separation, just before fermentation.

LIST OF SYMBOLS

SYMBOL	DESCRIPTION
a	annum
°C	degrees in Celsius
h	hour
kg	kilograms
kJ	kilojoules
l	litres
m	metres
m^3	cubic metres
mg	milligrams
mm	millimetres
mS	millisiemens
t	metric tonnes

ABBREVIATIONS

COD	-	Chemical oxygen demand
CIP	-	Cleaning-in-place
PO_4	-	Phosphate
PV	-	Permanganate value
SET.S	-	Settleable solids
SEV	-	Specific effluent volume
SPL	-	Specific pollution load
SS	-	Suspended solids
SWI	-	Specific water intake
TDS	-	Total dissolved solids
TOC	-	Total organic carbon

1 INTRODUCTION

The sorghum malting and sorghum beer brewing industries presently account for an estimated water consumption of 3,4 million m^3 annually. For malting sorghum grain, 630 000 m^3 of water are consumed in producing 185 400 t of malt annually. The SWI for malting is approximately 3,4 m^3 of water per ton of malt.

Breweries use a total of 2,75 million m^3 of water and produce 1,1 million m^3 of beer. This gives a specific water intake of 2,5 m^3 of water per m^3 of beer produced.

Malting of sorghum grains forms an integral part of the sorghum beer industry. The malting industry may be divided into 2 categories, 'industrial' and 'commercial'. Industrial maltsters provide the brewing industry with malt for the brewing process. Commercial maltsters produce packet malt and beer powder, which is sold directly to the consumers. In some instances, beer powder and packet malt are also produced by industrial maltsters. Industrial and commercial malting installations are in general different, commercial malting being usually less mechanized.

The effluent generated in the sorghum malting and brewing industries has a low pH with a high content of organic solids. Breweries discharge quantities of sorghum malt and grain, maize and sorghum grits, spent grain, dust, intermediate phases of brewing mixtures, sorghum beer, cleaning compounds, and boiler treatment chemicals. For sorghum malting and sorghum brewing, approximately 84% and 52% respectively of the total incoming water is discharged as industrial effluent.

Sorghum beer is produced at 36 breweries in South Africa, the National States and the Self-governing States (NS and SGS). A breakdown of the industrial production sources appears in Table 1.1.

Table 1.1 Industrial production source breakdown

Geographical area	Estimated production (1987) (m^3/a)	% of total production
Transvaal	439 000	39,9
Natal	276 000	25,1
Cape Province	79 000	7,2
Free State	106 000	9,6
NS & SGS	200 000	18,2
TOTALS	1 100 000	100

Sorghum beer is made from maize or sorghum grits, sorghum malt, yeast and water. It is highly nutritious (about 1 700 kJ/l) containing large quantities of minerals, proteins, carbohydrates and vitamin B, and has a low alcoholic content of about 3%. Sorghum beer's market price is roughly a quarter of the price of lager beer. Recent efforts to rationalize and privatize the industry, and the continuing development of pasteurization and new beers by the Council for Scientific and Industrial Research, indicate the possibility of high growth trends in the long term.

It is estimated that some 3,4 million m^3 of sorghum beer is drunk in total in South Africa and the NS and SGS each year. This is more than twice the volume of the annual barley beer consumption. The difference between the consumption and the industrial production represents a future market for the brewing and malting industries. A breakdown for sorghum malt usage is shown in Table 1.2.

Table 1.2 Sorghum malt usage

Destination	Malt quantity (t/a)	Beer Consumption (m^3/a)	% of total consumption	Malt to beer ratio
Breweries	50 000	1 100 000	32,5	22
Beer powder**	11 400	228 000	6,7	20
Home brewing*	124 000	2 058 000	60,8	16,6
TOTAL	185 400	3 386 000	100	

* Dry base malt is used for home brewing.

** Beer powder typically contains 33% malt. It is also mixed approximately in a 1.

The beer from the production lines of the breweries is either packaged directly and marketed in an active fermentation state, or allowed to ferment for 24 h. It may then be transferred to beer halls or other customers as bulk beer for consumption.
The sorghum malting and brewing industries are significant with respect to water and effluent. This is especially true when considering that the breweries are located largely in water scarce regions and often fall within the jurisdiction of small rural municipalities.

The information in this guide is based on detailed surveys of 5 sorghum malt manufacturers and 8 sorghum breweries.

2. PROCESS RÉSUMÉ

The process of converting sorghum grain into sorghum beer involves two distinct steps of malting the sorghum grain, and brewing the beer.

Industrial sorghum malting and brewing have short evolutionary histories when compared with that for barley. The technology and processes are mostly relatively new.

2.1 Tribal methods

Traditional methods vary considerably and one approach to malting and brewing is outlined here.

2.1.1 Malting

The sorghum grain is placed in a woven basket or sack and steeped in water. Germination is achieved by spreading a layer of the grain on a mat and covering it with leaves for a suitable period. The malt may then be sun dried, or used directly for brewing[7].

2.1.2 Brewing

Ground maize is mixed with boiling water in a pot and allowed to stand for a day. The mixture is then diluted with water and boiled for 2 to 3 h, and allowed to cool. An equivalent amount of ground sorghum malt is added, and the mixture stands for 24 h. Straining is effected with finely woven reeds, and the beer is then fit for consumption[7].

2.2 Modern methods

2.2.1 Malting

Two methods for malting sorghum exist: the 'commercial', 'floor' or 'open' method where the sorghum is simply laid out on the ground or on a floor, sprayed with water from hand-held hosepipes and turned over by hand; and the 'industrial' or 'box' method which is a mechanical process where the grain is contained in vessels and the flow of water is more easily controllable. The details described here are for the 'box' method.

The grain is steeped in water for three to four hours. Steeping rehydrates the grain embryo which in turn starts enzyme processes in the embryo and endosperm of the grain.

During steeping the moisture content of the grain will have risen to a desired level.

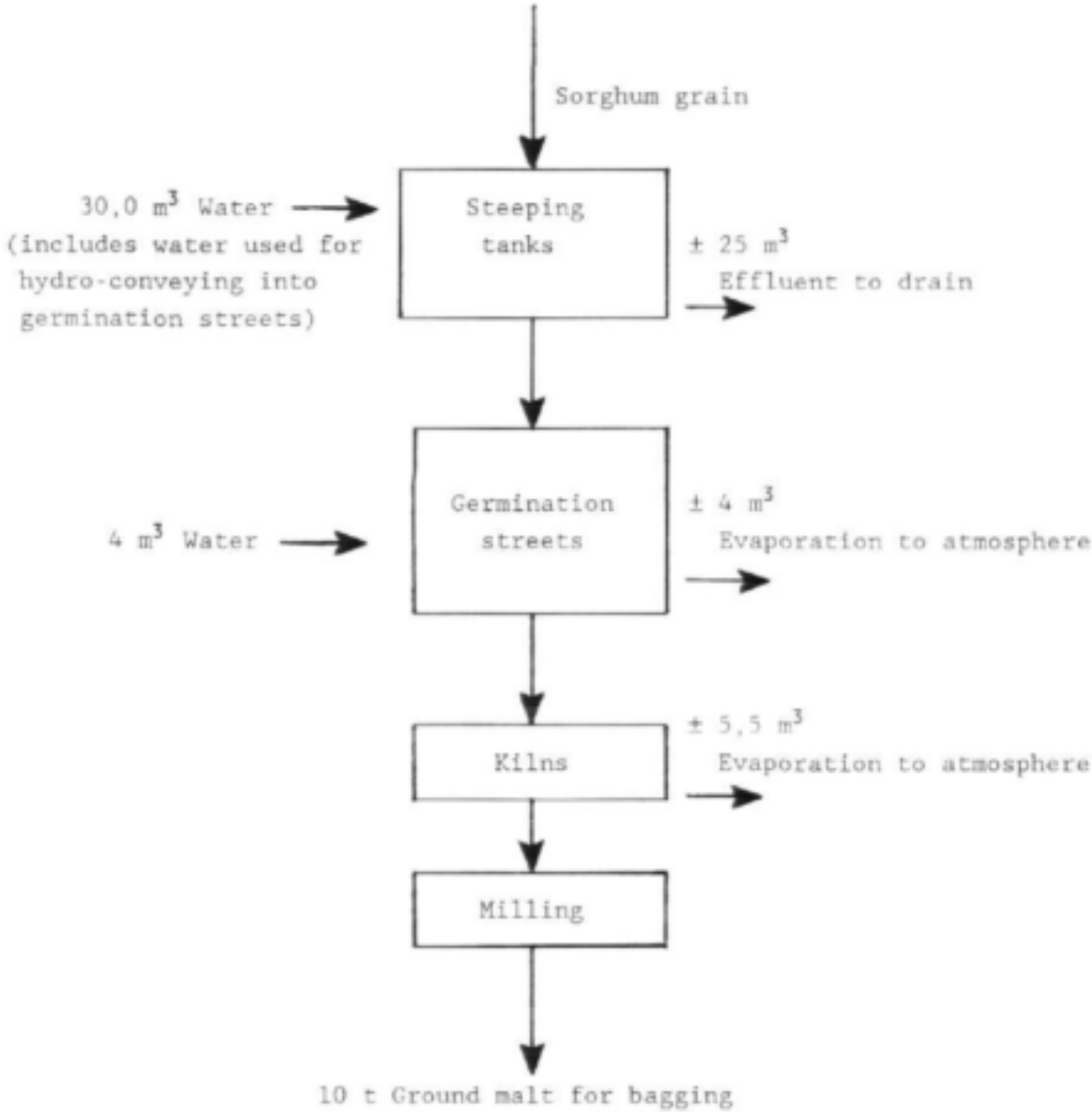
Following steeping the grain is pumped in a slurry to the germinating streets. These are long rectangular trays with perforated floors. The germinating street usually consists of six equal sectors along its length. The grain is transferred from one sector to the next (by mechanical means) every 24 h, and spends a total of 6 d germinating. Heat is generated during germination, and temperature is controlled by increasing or decreasing the flow rate of air blown through the perforated floor of the street. Water is periodically sprayed over the grain during germination to maintain its moisture content. Water is also used to humidify the air and this may result in wastage of water.

At the end of germination the malt is transferred to the drying kilns. Kilns dry the malt to a moisture content of about 8%, and the malt is kept in holding hoppers before being milled, packed in bags, and delivered.

Malting quality is critical to the success of the brewing process, and quality control is essential. Sorghum grain has a naturally low diastatic power when malted, and optimum conditions must be maintained to develop the amylases to the full. Temperature and moisture level are carefully monitored throughout the germinatory period.

Maltsters using high polyphenol or 'bird proof' grain (which represents about 20% of the total sorghum grain malted) add formaldehyde to their steeping tanks along with the grain and water. The formaldehyde inactivates the polyphenols which are contained in a layer just below the outer surface of the grain. This is essential to prevent the diastatic enzymes and the polyphenols reacting after the malt is ground. Formaldehyde is also used in certain instances as a disinfectant, as is lime.

Figure 1 Simplified block diagram of the industrial (mechanized) malting process



2.2.2 Brewing

Three methods of industrial brewing are prevalent in South Africa and NS and SGS. They are the 'Reef' (60%), the 'iJuba' (30%), and the 'Kimberley' (10%) recipes for brewing[1]. The brewing processes have similar microbiological and enzymatic principles of operation in common, and the 'Reef' method will be used to illustrate the sorghum brewing process.

Modern sorghum beer brewing plants consist of two sectors. They are the 'dry' material storage and mixing areas, and the 'wet' brewing section which is to be considered in detail.

Brewing is a batch process and the preparation of a 20 000 litre batch will be described here[1]. The brewing process is carried out by preparation of the wort (mashing), and fermentation. Sorghum beer brewing is carried out in two mashing and two fermentation steps, unlike the single mashing and fermentation used in barley brewing. Mashing and fermentation are also difficult to isolate as processes when describing sorghum brewing.

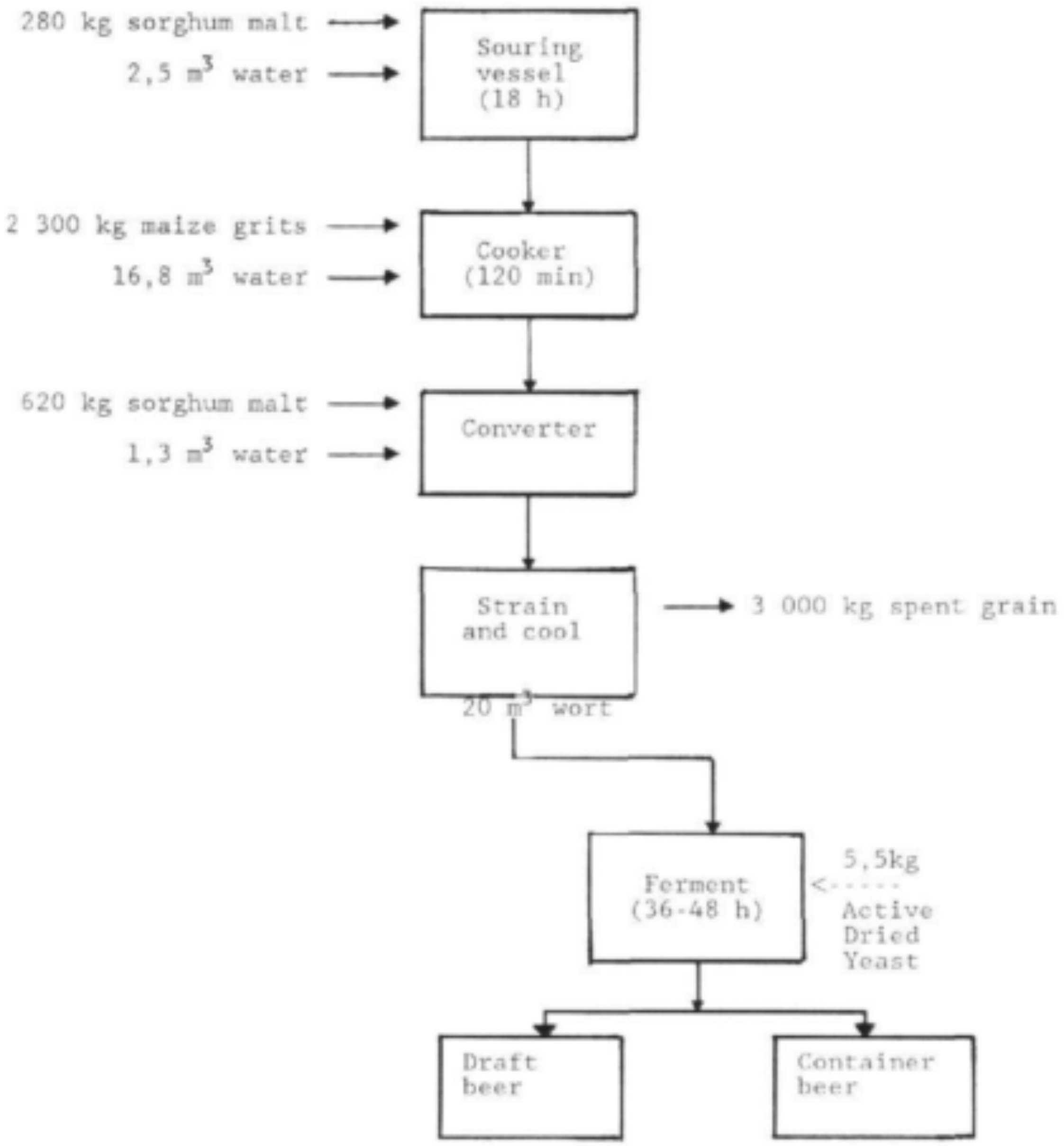
The first step in the brewing process is souring (see Figure 2). Approximately 280 kg of sorghum malt and 2,5 m^3 of water are mixed in a large steel vat. In some instances very small quantities of wheat bran, sorghum grain or maize grits may be added to the sour mixture. Electrical heating elements control the temperature at a constant value of about 48°C for between 16 and 48 h. This period depends on the malt quality, and whether the mixture is inoculated with previous sours or laboratory cultures. The souring process allows some solubilization of the malt, and the growth of thermophilic lactobacilli. Sugar and free amino nitrogen are produced, and these feed the lactobacilli. The lactic acid is used to control the pH during further brewing stages.

During souring the pH falls slowly at first, and then more rapidly. Souring is terminated at the required pH (about 3,3) as determined by measuring the brewers degrees. The quantity of sour added to the next stage is also calculated from the measurement of brewers degrees. Careful control of temperature is required during souring to prevent lactic acid bacteria destruction. Sours are normally produced in quantities which will supply about 6 brews.

The sour is pumped to a larger steel vessel where 2 300 kg of adjunct is added. Water is also added (16,8 m^3), the pH is increased to 3,6, and the mixture is boiled for 1,5 to 2,0 hours. This period may be reduced if the brew is pressure-cooked. Energy is supplied for cooking in the form of steam from a boiler which passes through coils within the cooking tank. During cooking under atmospheric conditions water is lost to atmosphere.

The adjunct is a source of starch and protein, and boiling gelatinizes the starch to allow a rapid breakdown by the malt amylases.

Figure 2 Simplified block diagram of the sorghum brewing process



After cooking, the mixture is cooled to 60°C. This may be achieved by pumping cooling tower water through coils within the cooker or by passing the cook through an external heat exchanger. It is then either converted within the cooker or piped to a converter.

For conversion, 620 kg of sorghum malt and 1,3 m^3 of water are added to the mixture. The pH at this point is critical to the final product and will normally have a value of approximately 4,0. At this stage the amylases begin to convert the starch to sugars. In barley brewing, the aim is to convert all the starch to sugar. In sorghum brewing, the low pH will limit the rate of starch hydrolysis. The remaining starch constitutes 'body' which is desirable in a sorghum beer.

The mash is pumped through a strainer where particles larger than 0,25 mm are removed. The spent grain contains about 62% moisture, has a low starch content, but is rich in protein.

The yield after separation of 20 000 litres of sorghum wort is pitched with 5,5 kg of active dried brewers yeast and cooled through a heat exchanger to 28°C and then pumped to holding tanks for packaging, or to fermentation tanks. On average, 69% of sorghum beer produced will be packaged directly. Packaging of sorghum beer can only be performed in the early stages of fermentation due to technical difficulties. The containers range from 1 to 50 litres in returnable and non-returnable vented types. The beer is ready for consumption about 3 days after the start of fermentation. In the absence of pasteurization the shelf life of sorghum beer is only about 5 days.

For bulk beer production the wort is held at 28°C for a 24-h fermentation period.

During fermentation, enzyme activities and also souring continues and the pH falls.

In both packaged and bulk beer, fermentation continues after the beer has left the brewery. For this reason breweries are built close to the point of consumption to reduce delivery time.

3. <u>SURVEY RESULTS</u>

The most important information extracted from the survey results is data on water intake, water usage, effluent and by-products.

3.1 Water intake

3.1.1 Malting

The degree of mechanization and rate of production varies considerably amongst maltsters, and this can be seen by the range of SWI in Table 3.1. Surveys include maltsters with production outputs of between 360 and 66 000 t/a.

Table 3.1 Sorghum malting SWI

Maltster	Average malt production (t/month)	Average water intake (m^3/month)	Specific water intake (m^3/t)
A	30	369	12,3
B	295	2 950	10,0
C	670	3 417	5,1
D	5 500	13 750	2,5
E	1 710	7 678	4,5
Averages	1 641	5 633	3,4 *

* 5633/1641 gives a weighted average SWI of 3,4.

From Table 3.1 the following points of interest are noted:

- The average SWI for malting is 3,4 m^3/t;
- SWI figures vary from 2,5 m^3/t to 12,3 m^3/t;
- Larger maltsters are considerably more water efficient than smaller ones;
- Using the average SWI and an overall production of about 185 400 t/a, the total water consumption for sorghum malting is estimated at 630 000 m^3/a.

Malting SWI s are to a large extent dependent on the degree of mechanization at the malting plant. The SWI is reduced considerably where mechanized indoor (industrial) malting methods are used. Maltsters C and E are mechanized while A, B and D are not. As can be seen, the SWI for Plants C and E is considerably lower than that for Plants

A and B. Plant D has an anomalous SWI because of its huge production rate which is over three times greater than the next largest plant included here. Also, when considering mechanized plants it must be remembered that SWI is a function of how close the plant is operating to capacity as well as efficiency of water management. SWI for non-mechanical processes does not exhibit this dependency on utilization of plant capacity.

3.1.2 Brewing

For sorghum beer brewing, the annual range of annual beer production varies between 13 200 and 187 500 m^3/a.

Table 3.2 Sorghum brewing SWIs

Breweries surveyed	Average beer production (m^3/month)	Average water intake (m^3/month)	SWI
A	1 100	3 080	2,8
B	1 200	3 120	2,6
C	1 250	4 000	3,2
D	1 540 *	7 392 *	4,8 *
E	1 963	4 514	2,3
F	4 332 *	17 761 *	4,1 *
G	5 010	13 527	2,7
H	15 611	37 420	2,4
Averages	4 356	10 944	2,5 **

** 10 944/4 356 = 2,5 (weighted average) excluding the outlying results marked*.

The following is evident on reviewing Table 3.2 above:

- the weighted average SWI for brewing is 2,5 m^3/m^3;
- the SWI varies from 2,3 to 4,8;
- larger breweries are not necessarily more water efficient than smaller ones; and

- using the average SWI and an overall production of about 1,1 million m^3/a, the total water consumption for sorghum brewing is estimated at 2,75 million m^3/a.

Two of the surveyed breweries (D,F) used borehole water as part of their overall water intake. In both instances the average water intake included the borehole water for the calculation of the SWI. Brewery F is an old plant and leaks were suspected in the underground pipework. The newest of the surveyed plants was brewery E, which had the lowest SWI.

As for malting, SWI is related to utilization of brewery capacity as well as to water management. Certain operations require the same amount of water to be used regardless of the production levels at the brewery and this will obviously result in higher SWI at production levels significantly lower than capacity. Most breweries are not operating at maximum capacity and SWI figures are therefore higher than would be expected at full production. Water management practices are instituted at most plants but methods are not uniform.

3.2 Water usage

3.2.1 Malting

The average breakdown of water use as derived from survey results is shown in Table 3.3.

Table 3.3 Malting water usage breakdown

Application	Estimated overall usage (m^3/a)	Average % of total usage	SWI (m^3/t)
Process	447 000	71	2,41
Washdown	113 000	18	0,62
Domestic	32 000	5	0,17
Boilers	38 000	6	0,20
Total	630 000	100	3,4

Table 3.3 shows that the majority of the water taken in is used directly in the process with washdown accounting for the second largest fraction. Process water in malting is defined as the water coming into contact with the sorghum grain during steeping and germination.

Process water may be further divided as follows:-

Steeping water	80%	(358 000 m^3/a; 57% of total)
Germination water	20%	(89 000 m^3/a; 14% of total)

Thus steeping water is the single largest water requirement for the malting industry and uses 57% of the overall industry's water.

On examining these figures, the reason for mechanized maltsters generally having a lower SWI becomes apparent. Assuming that only the flow of water to the steeping tanks is mechanically controlled, up to 80% of the process water is thus accurately supplied.

Washdown water also accounts for a significant proportion of the incoming water at 18% (113 000 m^3/a). This is mostly used for manual washing out of the germination street area with a hose. Small quantities of washdown water may also be used to clean out the steeping tanks and the surrounding area, and the plant in general.

Domestic and boiler usage are relatively small portions of the overall water breakdown.

3.2.2 <u>Brewing</u>

The breakdown of water usage in sorghum breweries from the survey results appears in Table 3.4. Process water is considered to be any water used directly in the souring, cooking or mashing processes.

Table 3.4 Breakdown of brewing SWI

Application	Estimated overall usage (m^3/a)	Average % of total usage	SWI
Process	990 000	36	0,90
Washdown	908 000	33	0,83
Boiler	248 000	9	0,23
Cooling	248 000	9	0,23
Packing	165 000	6	0,15
Bottle washing	110 000	4	0,10
Domestic	81 000	3	0,06
Total	2 750 000	100	2,5

Washdown water accounts for one-third of the total water intake. This includes water used for manual washing of tanks, floors and vehicles. Cleaning-in-place of process vessels is also included. Gardening and other miscellaneous uses are included in the domestic category.

Process water in sorghum brewing may be categorized further:

Souring : 14% (138 000 m^3/a; 5% of total)
Cooking : 79% (770 000 m^3/a; 28% of total)
Mashing : 7% (83 000 m^3/a; 3% of total)

Cooking can therefore be seen to account for the major portion of brewing process water, and is the second largest overall water user at 770 000 m^3/a.

3.3 Effluent

Effluent samples were taken at all the maltsters and breweries which were surveyed. Equivalent volumes of sample at a rate of 4 to 6 samples per hour were taken of the final industrial effluents. The samples were then mixed to form a composite sample, which was then analysed.

3.3.1 Malting

Table 3.5 gives an estimated effluent discharge as a percentage of the total water intake for the surveyed maltsters.

The SEV is listed in the last column. This relates the discharged effluent volume to the production of malt, and gives an approximate method of predicting effluent volumes from production figures.

Table 3.5 Malting : effluent discharge percentage

Maltster	Production (t/month)	Water intake (m^3/month)	Effluent discharge (m^3/month)	% of intake as effluent	SEV (m^3/t)
A	30	369	351	95	11,7
B	295	2 950	2 419	82	8,2
C	670	3 417	2 665	78	4,0
D	5 500	13 750	12 100	88	2,2
E	110	7 678	5 985	78	3,5
Average	1 641	5 633	4 704	84*	2,9**

* 4 704/5 633 x 100 = 84%

** 4 704/1 641 = 2,9 (weighted average)

The sorghum malting industry discharges approximately 84% of its water intake as industrial effluent to municipal treatment plants. This amounts to approximately 530 000 m^3/a.

Salient results for a typical analysis of the final effluent for sorghum malting are shown in Table 3.6.

Table 3.6 <u>Final effluent analysis - sorghum malting</u>

Determinand	Results (mg/l or specified)	
	Range	Typical
Conductivity @ 25°C	95 - 378	106
pH	4,9 - 6,8	5,0
COD	174 - 7 980	3 000
PV	28 - 1 170	260
SS	226 - 1 510	820
TDS	250 - 828	700
PO_4 - P	1,1 - 12,8	11,0

The relatively high suspended solids figure can be attributed to that part of the industry which is commercial or floor malting, i.e. not industrial malting. During the process of floor malting much larger quantities of SS are washed out.

SPL gives an indication of the quantity of pollutant in kg/t of sorghum malt produced (Table 3.7). The SPL may be multiplied by the malting production (t/months) to give the quantity of pollutant in the effluent in kg per month.

For a maltster with an average production of 1 641 t/month, the water intake would be approximately 5 633 m^3/month. Assuming 84% (Table 3.5) of the intake is discharged as effluent to a municipal treatment works, Table 3.7 gives monthly pollution loads. The total waste-water pollution load is also shown in Table 3.7.

Table 3.7 Sorghum maltsters pollution load

Determinand	SPL (kg/t)	Pollution load for a 1 641 t/month prod. (kg/month)
COD	8,6	14 100
PV	0,8	13 000
SS	2,4	3 900
TDS	2,0	3 300
PO_4 - P	0,03	52

The SPLs quoted above are based on an SWI of 3,4 and 84% of the water intake being discharged as effluent.

A sample of the steeping effluent was analysed and yielded the results shown in Table 3.8.

Table 3.8 Steeping effluent sample analysis

Determinand	Results (mg/l or specified)	
	Range	Typical
Conductivity @ 25°C	376 - 890	530
pH	4,0 - 6,7	4,9
COD	1 580 - 15 500	4 500
PV	152 - 3 100	400
SS	10 - 1 676	900
TDS	1 060 - 9 500	3 700
PO_4 - P	16 - 141	27

The steep water can account for up to 50% of the final effluent during sorghum malting. Treatment of sorghum malting effluent is often minimal and usually consists of a sedimentation tank to reduce the quantity of solids. These tanks often do not remove fine particles which wash off the grain during steeping.

3.3.2 Brewing

Table 3.9 shows an estimation of the industrial effluent as a percentage of the overall water intake for the surveyed breweries. Sorghum breweries generate an average of about 53% of their water intake as industrial effluent.

Table 3.9 Brewing : effluent discharge percentage

Brewery	Production (m^3/month)	Water intake (m^3/month)	Effluent discharge (m^3/month)	% of intake as effl. to drain	SEV
A	1 100	3 080	1 509	49	1,36
B	1 200	3 120	1 466	47	1,20
C	1 250	4 000	1 840	46	1,46
D	1 540 *	7 392 *	3 474 *	47 *	2,27 *
E	1 963	4 514	1 986	44	1,02
F	4 332 *	17 761 *	10 657 *	60 *	2,43 *
G	5 010	13 527	7 575	56	1,51
H	15 611	37 420	19 430	52	1,24
Average	4 356	10 944	5 634	52 **	1,29***

** 5 634/10 944 x 100 = 52% (weighted average excluding the outlying results marked *)

*** 5 634/4 356 = 1,29 (weighted average excluding the outlying results marked*)

Using a figure of 52% of the water intake discharged as effluent for the sorghum brewing industry, the total industrial effluent generated in sorghum brewing is estimated to be 1,43 million m^3/a.

The ratio of effluent to production (SEV) using the overall effluent and the production of the surveyed breweries is 1,29 m^3/m^3. A prediction on quantities of effluent for a specific capacity of brewery can be made by multiplying the production by the average sorghum SEV.

A comprehensive analysis was made of each of the 8 surveyed breweries final effluents, and the average results are presented in Table 3.10.

Table 3.10 Final effluent analysis - sorghum brewing

Determinand	Results (mg/l or specified)	
	Range	Typical
Conductivity @ 25°C	35 - 165	86
pH	4,4 - 6,8	5,1
COD	1 560 - 7 400	4 000
PV	190 - 590	350
SET. S	6 - 100	37
SS	580 - 2 300	1 300
TDS	560 - 4 500	1 800
PO_4 - P	1,7 - 7,0	4
Total Organic Carbon	350 - 1 680	760

Table 3.11 Pollution loads - sorghum brewing

Pollutant	SPL (kg/m^3)	Total industrial pollution load (kg/month)
COD	5,2	477 000
PV	0,5	46 000
SET.S	0,05	4 600
SS	1,7	156 000
TDS	2,3	211 000
PO_4 - P	0,01	920
TOC	1,0	92 000

The SPLs in Table 3.11 were calculated with an SWI of 2,5 and 52% of the water consumption discharged as effluent. The total industrial pollution load is based on a production of 1,1 million m^3/a. SPL gives a guideline as to the approximate quantity of pollutant that can be expected per m^3 of sorghum beer produced.

3.4 Effluent determinand ratios

The results given in Table 3.10 are based on a large number of sample analyses at the surveyed breweries. Ratios between the main pollution determinands have been derived and appear below:

1 PV : 2,0 TOC : 11,6 COD

Total organic carbon is likely to be used as a parameter to determine organic pollution loads in effluents in the future[2]. The following ratios are thus likely to be of use:
COD/TOC = 5,8 and PV/TOC = 0,5

3.5 Brewery by-products

Spent grain is generated by sorghum breweries when the wort passes through the separator. Typically a brewery will generate about 105 kg of spent grain (wet) for every m^3 of beer produced. Normally the spent grain is sold wet as an animal feed. If the grain is dried its mass can be reduced to 42 kg/m^3 of beer produced. The total output of wet spent grain for the sorghum brewing industry can be estimated at 115 000 t/a.

4. CONCLUSIONS AND RECOMMENDATIONS

The sorghum brewing industry is characterized by numerous small capacity plants in both industrial and rural areas. This is largely due to the short shelf life of the product. Sorghum beer is not normally pasteurized, and the yeast is not recovered from the beer as is the case in barley brewing.

The sorghum brewing industry sells its products at a low market price to customers who are often living at sub-economic levels. Expensive water saving and effluent treatment systems are therefore generally unsuitable for this industry. Also, skilled operators may be required which the industry often does not have available. The solutions that are required should therefore be cheap to purchase, install and maintain, and be cost effective in relation to the individual brewery's turnover.

Sorghum maltsters vary enormously in terms of their productions. Similarly, the water and effluent treatment systems that are suitable vary in cost, but there are simple measures which can be instituted throughout the industry.

In 1984, the Water Act of 1956 was extensively amended, effectively tightening up legislation and control on water consumption and effluent quality.[4,5] This was in response to critical drought conditions experienced within southern Africa. Industries response to this revised Act requires improved water management techniques using the latest available technology in parallel with revised staff training in water conservation and pollution matters.

Water and waste-water management must be seen as complimentary and should not be undertaken in isolation from each other if satisfactory results are to be achieved.

4.1 Water consumption

4.1.1 General survey deductions

The following is a list of significant data compiled from the surveys and presented in a summarized form:

- There are about 70 maltsters in the RSA and the NS and SGS producing about 185 400 t/a of sorghum malt which supply breweries, powder and dry base beer manufacturers in a 32 : 7 : 6 ratio respectively. Malsters use about 630 000 m^3 of water annually. The average SWI for sorghum malting is 3,4 m^3/t.

- Water used during steeping accounts for 358 000 m^3/a (57%) of the total malting water intake. Washdown (18%) and germination water (14%) are the next largest water consumers. For brewing, washdown water is the largest fraction at 908 000 m^3/a (33%), with cooking water (28%) using the second largest quantity.

- There are 36 sorghum breweries in the RSA and the NS and SGS with a total production of 1,1 million m^3/a. Brewing water use is about 2,75 million m^3/a. The average SWI for sorghum brewing is 2,5 m^3/m^3.

- Geographical distribution is such that 69% of the total production is in the Transvaal and Natal (see Table 1.1).

- Approximately 1,1 million m^3 of sorghum beer of an industrial origin is consumed annually. A further 2,3 million m^3 is estimated to be home brewed in rural areas.

- Thirty one percent of the production is delivered by tanker to beer halls and the remainder is packaged.

- The brewing water requirement as determined geographically can be seen in Table 4.1.

Table 4.1 Regional water intakes - sorghum brewing

Geographical area	Estimated water consumption (m^3/a)
Transvaal	1 100 000
Natal	690 000
Cape Province	195 000
Free State	264 000
NS and SGS	501 000
Totals	2 750 000

The total quantity of spent grain generated by the industry is estimated at 115 000 t/a.

4.1.2 Recommendations

For sorghum malting it is suggested that the target SWI should be 3,0 m^3/t for large and/or mechanized maltsters, and 7,0 m^3/t for a small maltster (less than 300 t/month).

The range of SWIs for sorghum brewing was found to be between 2,3 and 4,8 m^3/m^3 with a weighted average of 2,5 m^3/m^3 in the surveyed plants. An SWI target value of 2,0 m^3/m^3 is proposed.

It is reasonable to attempt to reduce the larger water using areas for the most effective water savings. These are the germination, steeping, washdown and cooking use of water. A reduction in water consumption in secondary processes should also be considered for further improvements to the SWI. It should be noted when considering the brewing and malting industries together, washdown and cooking water in brewing account for the largest overall proportion of water usage.

Suggestions on possible methods of reducing SWI which are common to both the malting and brewing industries are the following:

- Washdown water should be used extremely sparingly. A running 25 mm diameter hosepipe can consume up to 3,5 m^3/h. This can account for up to 106 m^3/month per hose, and will adversely affect the SWI. Pistol grips and other methods are a cheap addition easily installed to the end of the hose for cases where washdown water is essential.

- Water meters should be installed in suitable positions in the supply lines of the various sectors of the plants. The advantages are numerous and some are outlined below:

    - faulty water using machinery may be identified; and
    - faulty water management procedures may be identified.

  Meters should be read at frequent intervals and the consumptions, together with the main meters readings, should be cross-checked.

- Sweeping up of waste material should always be carried out instead of spraying the materials down the industrial effluent drain to form part of the effluent pollution load.

- Where possible, compressed air should be used for cleaning purposes in preference to a water hose if it does not constitute a noise problem.

- If water is essential in a particular washdown process, a high pressure low volume system may reduce the washdown water consumption by up to 35%.

- Water used in toilet facilities for workers is often excessive and should be monitored regularly.

- Judicious use of water for gardening at industrial plants is recommended.

- The possibility of leaking pipework, especially in older plants must not be overlooked as a reason for an excessive SWI.

- A general awareness of water conservation in both the management and working staff should prevail. The responsibility for water usage rests with every employee and they should be made aware of this.

- Incentive schemes for water conservation should be introduced.

In the case of malting, the following conservation methods are proposed:

- A mechanized water control system was observed to produce a considerably lower SWI in industry. A limiting valve for controlling the maximum flow rate of the water used for steeping will lower SWI considerably. The quantity of water used for steeping can be 57% of the total industry's requirement and a potential saving of, for example, 30% on this quantity by better control would result in a decrease of SWI by about 17%.

- An investigation into the possibility of better steeping techniques (including reuse if economically feasible) to save water and reduce effluent should be considered.

Water conservation in sorghum brewing may be achieved by the general measures listed earlier and the following:

- Install boiler condensate returns to reduce the evaporation losses to about 20%. Alternatively, hot condensate water may be used to replace municipal washdown water, saving similar quantities.

- Pressurized cooking reduces evaporation and increases production for the same water intake. Savings may also be achieved with the use of extrusion cooking of the adjunct presently being developed for maize grits by CSIR[1]. The steam efficiency of the process is superior to the existing cooking method and water and energy savings are expected to be greater than with pressure cooking.

- The 'Ijuba' process for brewing sorghum beer is 4% more efficient in terms of water than either the 'Reef' or 'Kimberley' methods.[1] The water savings for the entire sorghum industry using this method is about 45 000 m^3/a and the reduction of SWI is 1%. A limiting factor is the consumers resistance to product changes.

- Tanker washing water consumption is excessive at some breweries and this should be investigated. Pistol grips and high pressure low volume equipment, as well as staff training and supervision should be considered.

- Where returnable containers are used, the possibilities offered by washing water reclamation should be considered. Crate washing facilities should be optimized.

- Cascade rinsing of souring, cooking and conversion vessels should be encouraged.

Water may also be considered in terms of energy savings within a brewery. Cold municipal water should be used in preference to cooling tower water for cooling the wort and maintaining the fermentation temperature. The water may then be beneficially used at higher temperatures for souring and cooking. A small reduction in the SWI is also to be expected due to the reduced cooling tower evaporation loss.

4.2 Effluent

4.2.1 General survey deductions

Some of the relevant survey deductions are presented below:

- Sorghum maltsters and sorghum breweries discharge an average of 84% and 52% respectively of their total water intake as industrial effluent. This gives overall volumes of about 530 000 m^3/a and 1,43 million m^3/a respectively to be treated at municipal treatment works.

- Total evaporation for malting and brewing are estimated at 12% and 11% respectively of the total water intakes.

- Effluents for malting and brewing have high organic contents and a pH of about 5,0. CODs for malting and brewing are typically 3 000 mg/l and 4 000 mg/l and PVs are 260 mg/l and 350 mg/l respectively.

- Steeping effluent can constitute up to 50% of the overall maltsters effluent, and it may contain about 0,1% formaldehyde or lime.

- When considering specific pollution loads, the locations of sorghum breweries are particularly relevant. The quantity of PV (kg/d) discharged by a brewery may be as much as 4,5% of the total capacity of a small municipal effluent treatment plant.[4]

- The SPL for sorghum malting effluent was calculated to be an average of 8,6 kg COD/m^3. The sorghum brewing effluent SPL was found to be 5,2 kg COD/m^3.

- The average SEV for malting was found to be 2,9 m^3/t.

- The average SEV for brewing was found to be 1,3 m^3/m^3.

- The following relationships were deduced for sorghum brewery industrial effluents:

$$1 \text{ PV} : 2{,}0 \text{ TOC} : 11{,}6 \text{ COD}$$

and $$\text{COD/TOC} = 5{,}8 \quad \text{and} \quad \text{PV/TOC} = 0{,}5$$

Very few sorghum breweries or maltsters have any form of effluent treatment, and where treatment is carried out, it is usually inadequate. Individual breweries generally have small turnovers and the capital outlay for an elaborate treatment station would not be cost effective. However, there are cheaper measures which will reduce pollution loads, especially by means of better effluent management.

4.2.2 Recommendations

The following options are proposed to reduce the concentration of pollutants in the effluent, and improve and monitor all aspects of effluent disposal:

- Determine the pH, PV and other limits set out by the servicing municipality for industrial effluent.

- Establish the quality of effluent being discharged by the plant. This may be done by having a representative composite sample taken and analysed. Effluent qualities should be checked at regular intervals.

- Spilt sorghum grain in the case of malting or spent grain at breweries should be swept up rather than washed down the effluent drain. At sorghum breweries, spent grain is often conveyed into trucks for delivery, and large quantities of spillage are simply washed down as effluent. This is detrimental to the pollution load and reduces the mass of spent grain available for sale as cattle or pig feed.

- A minimum quantity of remaining fluids should be washed out of pipes and vessels to drain. Time is required to empty pipes and vessels to the fullest extent between brewing phases.

- Large quantities of wort are often spilt and wasted in brewery packaging halls. This is then washed down, using considerable quantities of water. Drip collection trays at critical points below the packaging machine are therefore recommended to retrieve the wort which could be added to brewing batches just before the cooking phase.

- The installation of some form of static, rotating or vibrating screen will further reduce the solids content of the effluent, and the possibility of supplementing spent grain with this requires investigation. It has been found to reduce the COD and PV values by 21% and 17% respectively in the effluent of a sorghum brewery.[4]

- A high-rate anaerobic treatment system is presently being used for treatment of barley brewing effluent. Adaptations of this in a smaller and cheaper version may well be suitable for sorghum brewing.

- Effluent from all sectors of a brewing or malting plant should be collected in a suitably sized tank for balancing before being disposed of to a municipal drain. Balancing of effluent provides the following advantages:

  - High strength effluents are diluted.
  - Low and high pH effluents mix.
  - A steady effluent flow may be achieved.
  - Shock effluent loads on municipalities are reduced.

Sizing of balancing tanks is critical for correct operation. A low pH may be corrected by the addition of alkali to the balancing tank.

- Target SPL figures for malting and brewing are proposed at 7,0 kg COD/t and 5,0 kg COD/m^3 respectively.

5. REFERENCES

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