Natsurv 5:

Water and wastewater management in the sorghum beer industry

(Edition 2)

N. Musee

WATER RESEARCH COMMISSION

TT 692/16

NATSURV 5: WATER AND WASTEWATER MANAGEMENT IN THE SORGHUM BREWING INDUSTRY (EDITION 2)

N MUSEE

Report to the

WATER RESEARCH COMMISSION

by

Department of Chemical Engineering
University of Pretoria, South Africa

WRC Report No. TT 692/16

December 2016

WATER
RESEARCH
COMMISSION

Obtainable from

Water Research Commission
Private Bag X03
Gezina, 0031
Republic of South Africa

This report emanates from a directed proposal sought by the Water Research Commission, *Revision of Natsurv 1: Water and Wastewater Management in The Sorghum Brewing Industry (Edition 2).* (WRC Project No. K5/2384).

This is an updated and revised version of Natsurv 1 that was published in the Natsurv-series in 1989 as WRC Report TT 39/89.

ISBN 978-1-4312-0857-9
Printed in the Republic of South Africa

EXECUTIVE SUMMARY

This guideline aim is to update the First Edition of National Survey 5 (Natsurv 5) of 1989 on aspects related to resources management in the traditional sorghum beer industry. Sorghum beer industry is a sub-category of beverage industry, and therefore, resources such as water, agricultural based raw material (sorghum cereals), energy and waste management are essential to achieve optimal operations and viability. The guideline outlines industrial operations, degree to which various resources have been managed based on a set of indicators per unit of production (e.g. specific water intake, specific effluent volume, etc.), best practices adopted or currently under implementation, and finally, an outline of recommendations on probable improvements that can further enhance resources utilization in the sorghum beer industry. One key feature on the changes observed in this industry is its significant decline both in size (e.g. number of malting and brewing plants), and volume of beer produced annually since the First Natsurv 5 Report of 1989 was published.

For almost two decades, the sorghum beer industry in South Africa has experienced a number of acquisitions, and in particular, recent changes in 2013 have brought into sharp focus on optimization of resources utilization. Among the reasons for these changes are a response to water scarcity in South Africa, rising constraints in energy supply, increasing market competition from other beer-based beverages, and onerous legislative framework aimed to project human health and the environment. The changes are highlighted in the report as, and the extent to which they have been implemented using a suit of key indicators, and the degree to which they compare to international benchmarks in terms of accounting for water and energy utilization; aspects which were previously not considered. In brief a comparison of water, wastewater, waste, and energy management practices for this survey and that of 1989 in the tables below.

Survey results for 1989 and 2016 on resources consumption and waste generation in the sorghum beer brewing plants.

Parameter (units)	1989 Survey Findings			2016 Survey Findings		
	N[1]	Range	Annual/ Mean	N[1]	Range	Annual/Mean
Beer production – (KL/y)	33[2]	-	1 100 000	4	32 700-93 100	241 300
Water consumption – (KL/y)	8	37 400-449 000[a]	2 750 0000[a]	4	114 000-333 910	759 500
Specific water intake – (L/L)	8	2.4-4.8[a]	2.5[b]	4	3.19-3.90	3.54
Effluent discharge (KL/y)	8	17600-233 200[a]	1 430 000[b]	4	56 000-204 400	483 700
Effluent to water intake (%)	8	44-60[a]	52[b]	4	48.2-76.5	63.7
Specific effluent volume – (L/L)	6	1.02-1.51 [a]	1.29[b]	4	1.54-2.92	2.26
Chemical oxygen demand (mg/L)	8	1 560-7 400	4 000	1	1654-2 530	2 022
COD pollution load (kg/month)	8	-	477 000	1	-	25 010
Specific pollution load – COD (kg/m^3)	8	-	5.2	1	-	3.01
Total dissolved solids (mg/L)	8	560-4 500	1 800	1	200-1 239	1 239
TDS pollution load (kg/month)	8	-	211 000	1	-	15 332
Specific pollution load –TDS (kg/m^3)	8	-	2.3	1	-	1.85
Settleable solids (mg/L)	8	550-2 300	1 300	1	4.50-60	15
SS pollution load (kg/month)	8	-	156 000	1	-	189.40
Specific pollution load –SS (kg/m^3)	8	-	1.7	1	-	0.02
SEC – (KWh/ 1000 L)	-	-	-	4	0.058-0.070	0.062
pH	8	4.4-6.8	5.1	1	3.20-5.33	3.86

Notes:

1. Number of brewing or malting plants in a given survey.
2. Values were reported for a region and not specific breweries
3. In this study, since only one malting plant is the supplier to all brewing processing plants, no range values are provided. This is to ensure consistency of reported values in this table.
4. Symbols *a* and *b* implies, the inclusion of outlier values in the range and exclusion of outlier values in determining the weighted average, respectively.

Survey results for 1989 and 2016 on resources consumption and waste generation in the sorghum malt brewing plants.

Parameter (units)	1989 Survey Findings			2016 Survey Findings		
	N[1]	Range	Annual/ Mean	N[1]	Range	Annual/Mean
Malt production – (t/y)	5	360-66 000	185 400	1	-	9 100
Water consumption – (KL/y)	5	4400-165 000	630 000	1	-	71 300
Specific water intake – (L/kg)	5	2.5-12.3	3.4	1	-	7.85
Effluent discharge (KL/y)	5	4200-145 000	530 000	1	-	32 205
Specific effluent volume (L/kg)	5	2.2-11.9	2.9	1	-	3.55
Chemical oxygen demand (mg/L)	5	1 580-15 500	4 500	1	-	-
COD pollution load (t/month)	5	-	14 100	1	-	-
Specific pollution load – COD (kg/t)	5	-	8.6	1	-	-
Total dissolved solids (mg/L)	5	1 060-9 500	3 700	1	-	-
TDS pollution load (t/month)	5	-	3 300	1	-	-
Specific pollution load –TDS (kg/t)	5	-	2.0	1	-	-
Settleable solids (mg/L)	5	10-1 676	900	1	-	-
SS pollution load (t/month)	5	-	3 900	1	-	-
Specific pollution load –SS (kg/t)	5	-	2.4	1	-	-
SEC – (KWh/ 1000 L)	5	-	-	1	-	0.0292
pH	5	4.0-6.7	4.9	1	-	-

From these results, the following inferences can be made.

1. That the annual beer production has decreased by about 5-fold as the number of brewing and malting plants declined from 33 and 5 to 4 and 1 in 1989 and 2016, respectively.
2. The average specific water intake (SWI) and specific effluent volume (SEV) per litre of sorghum beer produced (for beer and malt produced) increased over time. It was unclear why but possibly due to closure of bigger breweries and malting plants since the larger the production volume is normally accompanied by lower water consumption.
3. The COD, TDS and SS values for the effluent data analysed in this study were lower compared to those reported in 1989. These were attributed to economic- and legislative-driven push factors. pH in this study was found to be lower than the value of 1989.
4. Both the annual water used and effluent generated (on overall aggregated values) decreased in 4-, and 3-folds, respectively.
5. Due to increasing pressures on resources (e.g. energy), in this report, energy required in brewing and malting processes has been reported for the first time.
6. Specific pollution load (SPL) was only calculated for one brewery plant in this study. With that in mind, it appears the effluent load has been reduced considerably. This can be attributed to economic and legislative (by-laws) reasons as effluent pollution load is used as basis of calculating effluent charges released for treatment in publicly owned wastewater treatment plants.

Overall, with the ongoing process of improving the sorghum beer industry through modernization (e.g. automation of certain processes), adoption of best practices such as using cleaning-in-place (CIP) as is the practice in the broader beverage industry, adoption of stringent accounting systems for process resources, and training of personnel, it is likely that the performance of water, energy and waste management in this industry will improve considerably.

ACKNOWLEDGEMENTS

The author wishes to thank the Water Research Commission for the funding support of the project, the National Sorghum Beer Breweries (Pty) for the provision of data used in developing the guideline, and numerous interviews to offer insights on the operations of traditional sorghum beer industry. The contributions of Mr Anesh Maharaj (UNB) to the project as well as Mr Delrich Stander and Ms Fhumulani Ramukhwatho are also gratefully acknowledged. The author acknowledges the contributions of the following people for their contributions to the project.

Reference Group	**Affiliation**
Dr Jo Burgess	Water Research Commission
Mr Anesh Maharaj	United National Breweries
Dr David Harcourt	Private Consultant

This page was left blank deliberately

CONTENTS

EXECUTIVE SUMMARY ... iii

ACKNOWLEDGEMENTS ... v

CONTENTS ... vii

LIST OF FIGURES ... ix

LIST OF TABLES ... ix

ACRONYMS & ABBREVIATIONS ... x

GLOSSARY ... xi

1. background ... 1

1.1. SORGHUM BEER INDUSTRY: AN OVERVIEW ... 1
1.2. GROWTH PROJECTIONS ... 2
1.3. PROJECT AIMS ... 3
1.4. SCOPE AND LIMITATIONS ... 4
1.5. METHODOLOGY ... 4
1.5.1. Literature review ... 4
1.5.2. Identification of sorghum brewing and malting plants ... 4
1.5.3. Use of questionnaires, site visits, and interviews ... 4

2. PROCESS OVERVIEW: SORGHUM BEER BREWING ... 5

2.1. INTRODUCTION ... 5
2.2. TRADITIONAL BEER PRODUCTION PROCESS ... 5
2.2.1. Malting ... 5
2.2.2. Brewing ... 5
2.3. INDUSTRIAL BEER PRODUCTION METHODS ... 5
2.3.1. Malting procedure ... 7
2.3.1.1. Steeping ... 7
2.3.1.2. Germination ... 7
2.3.1.3. Drying ... 7
2.3.2. Brewing procedure ... 7
2.3.2.1. Souring ... 7
2.3.2.2. Adjunct cooking ... 7
2.3.2.3. Primary mashing ... 8
2.3.2.4. Secondary cooking (heating) ... 8
2.3.2.5. Secondary mashing ... 8
2.3.2.6. Straining ... 8
2.3.2.7. Cooling ... 8
2.3.2.8. Packaging ... 8

3. POLICIES, REGULATIONS, AND BYLAWS ... 9

3.1. INTRODUCTION ... 9
3.2. WATER POLICY FRAMEWORK ... 9
3.2.1. National Water Acts ... 9
3.3. HEALTH AND SAFETY POLICY FRAMEWORK ... 10
3.4. TRADE AND LICENCING POLICY FRAMEWORK ... 10
3.5. ENVIRONMENTAL POLICY FRAMEWORK ... 10
3.6. BY LAWS AND TARRIFS ... 11

3.6.1. City of Tshwane Municipality ... 11
3.6.1.1. Normal Conveyance and treatment cost ... 11
3.6.1.2. Extraordinary Treatment Cost ... 11
3.6.1.3. Non-compliance with By-Law limits ... 11
3.6.2. eThekwini Municipality ... 12
3.7. CONCLUDING REMARKS ... 12

4. WATER USE AND MANAGEMENT ... 13

4.1. INTRODUCTION ... 13
4.2. WATER CONSUMPTION ... 13
4.2.1. Water consumption: brewing processes ... 13
4.2.2. Water consumption: malting process ... 15
4.3. WATER QUALITY ... 15
4.3.1. Water quality: brewing processes ... 15

5. WASTEWATER generation AND MANAGEMENT ... 17

5.1. EFFLUENT GENERATION AND QUALITY: BREWING PROCESSES ... 17
5.1.1. Effluent generation ... 17
5.2. EFFLUENT GENERATION: MALTING PROCESS ... 18

6. ENERGY CONSUMPTION AND WASTE GENERATION ... 20

6.1. INTRODUCTION ... 20
6.2. ENERGY CONSUMPTION ... 20
6.2.1. Energy consumption: brewing processes ... 20
6.3. WASTES GENERATION ... 22
6.3.1. Waste generation: brewing processes ... 22
6.3.2. Waste generation: malting process ... 23

7. BEST PRACTICES FOR WATER USE AND WASTEWATER MANAGEMENT ... 25

7.1. WATER USE AND WASTEWATER MANAGEMENT: PREAMBLE ... 25
7.1.1. Technology-based approaches ... 25
7.1.2. Operational practices-based approaches ... 26
7.1.3. Reuse-, recovery- and recycling-based approaches ... 27
7.2. WATER MANAGEMENT TOOLS AND APPROACHES ... 28
7.2.1. Water pinch analysis ... 28
7.2.2. Water footprinting ... 28
7.2.3. Life cycle assessment ... 29
7.3. VALUE CHAIN ENVIRONMENTAL RESPONSIBILITY APPROACH ... 29

8. CONCLUSIONS & RECOMMENDATIONS ... 31

8.1. CONCLUSIONS ... 31
8.2. RECOMMENDATIONS ... 31

REFERENCES ... 32

APPENDIX A1: BEER PRODUCTION, WATER CONSUMPTION, AND EFFLUENT GENERATION IN BREWING AND MALTING PLANTS ... 35

APPENDIX A2: MAINS WATER AND EFFLUENT QUALITY IN MALT BREWERIES ... 38

LIST OF FIGURES

Figure 2.1: Generic industrial brewing processes for sorghum beer production (Taylor, 2004). 6
Figure 7.1: Waste management hierarchy based on Pollution Prevention Act (US Congress, 1990)........... 25

LIST OF TABLES

Table 1.1: Reported sorghum beer production and processing plants 2
Table 1.2: Quantities of South African sorghum consumption in different market segments 3
Table 4.1: Summary of water consumption and distribution in industrial brewing plants and beer produced 13
Table 4.2: Water consumption in litres per 1000 litres of beer produced in sorghum beer brewing plants 14
Table 4.3: Water consumption during the malting processes over eight months 15
Table 5.1: Summary of average effluent generation from sorghum brewing processes over eight months, and estimated annual volume 17
Table 5.2: Summary of effluent quality parameters over three months from brewery A 18
Table 5.3: Effluent generated from the malting processes over eight months 19
Table 6.1: Energy consumption in sorghum beer industry for every 1000 litres of beer produced (KWh) 20
Table 6.2: Different sources of energy and their respective quantities used in four breweries....................... 21
Table 6.3: Conversion of various energy units into joules... 21
Table 6.4: Results of energy use ratio (EUR) for four brewing plants.. 21
Table 6.5: Distribution and quantity of energy from various sources used in the malting plant 22
Table 6.6: Waste generation per 1000 L of beer produced from different streams 23
Table 6.7: Waste generation per ton of malt produced for different forms of waste streams 23
Table A1.1: Beer production and water consumption in months eight months (July 2015 to February 2016) 35
Table A1.2. Effluent generation in eight months (July 2015 to February 2016), and the estimation of specific volume (SEV). 36
Table A1.3. Waste generation from brewing plants for eight months (July 2015 to February 2016), and each type per 1000 L of beer produced. 37
Table A2.1: Municipal main water quality over 3 months used in sorghum beer brewing plants.................... 38
Table A2.2: Effluent characteristics over 3 months generated from sorghum beer brewing plants................ 39

ACRONYMS & ABBREVIATIONS

BIER	Beverage Industry Environmental Roundtable
CIP	Cleaning-in-place
COD	Chemical oxygen demand
DAFF	Department of Agriculture, Forestry and Fisheries
DEA	Department of Environmental Affairs
DTI	Department of Trade and Industry
DL	Department of Labour
EUR	Energy use ratio
EWS	eThekwini Water and Sanitation Unit
FY	Financial year
NATSURV	National Industrial Water and Wastewater Survey
NEMA	National Environmental Management Act (Act No. 107 of 1998)
NSB	National Sorghum Breweries
NWA	National Water Act (Act No. 36 of 1998)
OA	Oxygen absorption
OHSA	Occupational Health and Safety Act (Act No. 54 of 1972)
SAB	South African Breweries
SCI	Specific coal intake
SEC	Specific energy consumption
SEV	Specific effluent volume
SPL	Specific pollution load
SS	Settleable solids
SWI	Specific water intake
TBI	Traditional Beer Investments
TDS	Total dissolved solids
TOC	Total organic carbon
TS	Total solids
UNB	United National Breweries
WSA	Water Services Act (Act No. 108 of 1997)
WUR	Water use ratio

GLOSSARY

ADJUNCT	a starchy cereal source (normally maize grits) upon which the amylase enzymes act.
AMYLASES	a group of enzymes which degrade starch to sugar.
BEER POWDER	a cereal mixture sold in packets for dilution with water and fermentation.
BULK BEER	a beer which is not packaged but sold in bulk to customers.
COMMERCIAL MALTSTER	a term referring to maltsters who supply malt to home brewing market.
COOK	a brewing mixture just before *or* after the cooking phase.
EFFLUENT	a liquid stream flowing from a specific industrial process or unit operation.
ENZYME	a biochemical catalyst produced by living cells.
INDUSTRIAL MALTSTER	a mechanized indoor malting plant which supplies malt to sorghum beer breweries.
INOCULATION	to the addition of a bacterial culture to start the lactic acid fermentation process.
MALT	sorghum grain after germination and drying.
MASHING	the process involved in the preparation of the wort.
RECYCLE	the use, reuse or reclamation of a material so that it re-enters the industrial process or used elsewhere rather than become a waste after serving its original purpose.
REUSE	use of a raw material (specific process input) more than once.
SOLUBILIZATION	first stage of mash conversion induced by enzyme activity.
SOURCE REDUCTION	reduce the amount of waste generated at source by changing design, operations manufacturing, or reuse of materials to minimize the quantity of waste generated.
SOURING	acidification process brought about by lactic acid bacteria.
SPECIFIC EFFLUENT LOAD	mass of a particular/specific pollutant in the effluent per unit of production.
SPECIFIC EFFLUENT VOLUME	quantity of effluent generated per unit of production.
SPECIFIC ENERGY CONSUMPTION	quantity of energy used per unit of production.
SPECIFIC WATER INTAKE	quantity of water used/consumed per unit of production.
STARCH HYDROLYSIS	conversion of starch to sugar.
STEEPING	a preliminary soaking of sorghum grain to rehydrate the embryo.
WASTE STREAM	continuous flow of waste (liquid, gaseous or solid) from either an activity, or process.

WATER FOOTPRINT	total volume of water used to produce the goods and services consumed by a specific entity or area.
WORT	the mixture at the end of mashing and after spent grain separation, just before fermentation.

1. BACKGROUND

1.1. SORGHUM BEER INDUSTRY: AN OVERVIEW

Sorghum beer was used during marriages, funerals, reconciliations, adulthood ceremonies, and child birth in Southern Africa (including South Africa) for centuries , and therefore, often regarded as a traditional alcoholic beverage in many cultures (UNB Presentation on Liquor Bill, 2003). In 2009, the industrially produced sorghum beer was approximated to account for 8% of the total commercial liquor sales in South Africa by the Industry Association for Responsible Alcohol Use (ARA) (ARA, 2009). On the other hand, domestic (home brewed) sorghum beer produced and sold accounted for two-thirds of the total sorghum beer production and sold in South Africa (ARA, 2009).

The dominant market player in the sorghum beer industry in South Africa – the United National Breweries (UNB) – controls both the distribution network and raw material sourcing – with a market share of 95-100% (UNB Presentation on Liquor Bill,2003) of the industrial beer production. The National Sorghum Breweries (NSB) was established in 1970 wholly government owned, had 8 big breweries with average monthly production of 20 million litres per month, and was bought managed by UNB (United National Breweries, 2013) in 1997. NSB had beer halls (owned by municipalities) but these were all closed between 1994 and 2000 which lead to all commercial traditional sorghum beer in the market to be packaged. Over the same period, small brewers with monthly production of 2.5 million litres and lower were also closed as they were not profitable. In 2000, the UNB purchased the Traditional Beer Investments (TBI) – the sorghum division of South African Breweries (SAB) (A&T Consulting and Eckart Naumann, 2005), and at the time TBI operated 8-10 breweries. This acquisition made UNB control over 90% of the local commercial sorghum beer market in South Africa. By 2005, the UNB had an estimated annual production of 400 million litres of sorghum beer (A&T Consulting and Eckart Naumann, 2005).

Presently in South Africa, sorghum beer production consists of four operating breweries owned by UNB, and one raw material production and distribution. Notably, the sorghum beer brands are each tailored to meet either a variety or specific consumers' tastes and preferences. The brands includes: Ijuba Special, Ijuba Blue, Leopard Special, Chibuku, and Tlokwe (UNB, 2013) – and a powder version produced by commercial maltsters for the production of traditional beers. Due to lack of data for resources utilization in commercial maltsters that supplies home brewers, and more importantly, to allow systematic life cycle assessment and accounting of resources used in the sorghum beer industry, the focus is on brewing and malting plants for commercial traditional sorghum beer. This would aid to, for example, determine quantities of waster or energy required to produce one litre of commercial traditional beer from malting production stage to the packaged beer excluding energy used for the distribution of malt from the malting plant to the brewing plants.

Since 1990s after the publication of the First Edition of Natsurv 5 (Steffen, Robertson & Kirsten INC Consulting Engineers, 1989), the sorghum beer brewing industry has experienced a significant number of changes that includes but not limited to: form and/or type of raw material used, operational changes, and introduction of improved technologies for wastewater and waste treatment. Owing to sustained increases in cost of: fuel oil, raw materials including freshwater, treatment and discharge of wastes, and electricity has compelled the sorghum brewing industry to reduce production costs by intensifying their production processes. This have been achieved over the years through consolidation and modernization of malting and brewing plants in order to improve water, energy, raw material use, and increased production yield. In addition to these economic challenges, regulatory framework governing beer industry has become more onerous, and particularly in South Africa. For example, the industry has to comply with increasing number of National Acts, Strategies on resources consumption, specific Provincial and local By-laws in areas of their operations. In addition, the regulatory framework in the brewing industry extends beyond the production phase, for instance, to other chain-value adding phases such as: distribution, labelling, packaging, advertising, trade and pricing practices, and alcohol content (Goldammer, 2008). However, the later form of regulatory requirements will not be considered in details as the case for the former as they are beyond the scope of this project.

1.2. GROWTH PROJECTIONS

To ascertain the industry growth prospects, literature review was carried out from 1980s to 2016. Results suggested that although the amount of traditional sorghum beer produced by home brewers was several 2-folds the commercial industrial production; overall, the sorghum beer market declined at an average rate of 5-6% per annum (UNB Presentation on Liquor Bill, 2003). Thus, over the last twenty seven years in South Africa there has been a steep decline of sorghum beer industry. This is due to two key factors. First, was self-industry imposed banning of packaging beer in 20 litre kegs. This is because the quality and hygienic standards of the beer could not be guaranteed particularly during the distribution phase. However, to address the declining trend in sorghum beer market, packaging of beer in 20 litres kegs has recently been adopted, and consequently, there are signs of sales growth but not to previous figures of 1980s and early 1990s.

Secondly, in South Africa; there has been steep market competition largely underpinned by changes in societal norms and practices partly due to rising average income per capita which has shifted beer demand on western alcohol brews with higher absolute alcohol concentration (Parry and Bennetts, 1998). As a result, the consumer shift towards clear malt beer brands has led to a decline in demand for sorghum beer (UNB Presentation on Liquor Bill, 2003; Peltzer and Ramlagan, 2009; DAFF, 2012). For example, there were nine large-scale sorghum beer breweries in 2004 (DTI, 2004) and 20 microbreweries as of 2003 (UNB Presentation on Liquor Bill, 2003) but presently (2016) are only four large sorghum beer brewing plants.

Results from the literature and summarized in Table 1.1 show the number of traditional sorghum beer processing plants owned by the UNB having declined from 12 breweries (UNB Presentation on Liquor Bill, 2003) to 4 breweries in 2016 (this study shows a 67% decrease in number of brewing plants) with corresponding reduction in sorghum beer volumes production from 425 and 214 million litres (a 49.6% decline), respectively. In addition, the declining trend on sorghum beer industry was also evident from data on quantities of sorghum processed for malt (both indoor and floor as shown in Table1.2). Data indicates that sorghum processed for human consumption declined from 69% (1997/8) to 46% by 2009/10 (NAMAC, 2003; DNA Economics, 2013). Of interest is the indoor malt (Table 1.2) used for commercial traditional sorghum beer brewing.

Table 1.1: Reported sorghum beer production and processing plants.

Year	Malting plants	Processing plants	Sorghum beer (litres)* (p/a)	Market decline p.a.	Reference
1989	70	33	1 100	-	Steffen, Robertson & Kirsten INC Consulting Engineers, 1989
2003	1	12	425	5-6%	UNB Presentation on Liquor Bill, 2003
2005	1	9	400	-	A&T Consulting and Eckart Naumann, 2005
2010	1	7	-	-	Econex and Quantec Research, 2010
2010	1	5	348	-	DTI Report, 2011
2016	1	4	214	-	This study, 2016

*sorghum beer in million litres; p/a: per annum.

Table 1.2: Quantities of South African sorghum consumption in different market segments

Year	Human consumption				Animal feed	Total domestic	Export	Annual % Δ for indoor
	Indoor malt	Floor malt	Meal	Rice, grits, other				
1997/98	36 270	87 286	53 373	2 410	63 727	243 066	57104	-
1998/99	38 900	81 500	52 800	3 300	58 200	234 700	58 100	7.3
1999/00	28 300	85 900	56 700	3 000	36 400	210 300	23 500	-27.2
2000/01	32 800	90 400	61 200	1 800	23 300	209 500	39 900	15.9
2001/02	28 700	84 300	75 800	1 100	16 200	206 100	48 200	-12.5
2002/03	20 500	74 900	77 900	1 100	21 900	196 300	66 200	-28.6
2003/04	21 100	73 900	73 700	200	10 100	179 000	48 800	2.9
2004/05	25 600	76 400	76 800	200	10 000	189 000	37 600	21.3
2005/06	24 600	78 300	87 900	100	12 000	202 900	38 200	-3.9
2006/07	25 400	70 100	86 000	100	8 000	189 600	27 800	3.3
2007/08	24 900	65 200	95 100	-	10 800	196 000	27 300	-2.0
2008/09	22 200	64 100	91 100	-	9 700	187 100	37 100	-10.8
2009/10	20 100	63 300	98 600	-	7 900	189 900	52 000	-9.5

*all values are in tons. Source: DNA Economics, 2011

Data indicated a decline from 36 270 tons in 1997/98 to 20 100 tons by 2009/10 of sorghum used for industrial beer brewing. The change in the consumption of indoor sorghum with 1997/98 taken as base year indicated an annual average decline of 3.7%. Assuming the same rate of decline (3.7%) continued post 2009/10, we estimated the indoor sorghum consumption for 2014/15 to be approximately 16 634 tons. This estimate was in the same order as the annual figure provided by an industry expert of 14 000 tons of sorghum used in industrial sorghum beer production. Therefore, both the estimated and expert's values are in good agreement, and the small difference may have been due to beer production from smaller brewing plants for the former case. The difference in these two estimates may point to a more severe decline of the industry as the expert value was based on current sorghum usage in industrial beer brewing. First Edition of Natsurv 5 (Steffen, Robertson & Kirsten INC Consulting Engineers, 1989) reported an annual sorghum beer production in South Africa to be 1 100 million litres. Again, by comparing sorghum beer volumes of 1989 and 2016 point to sorghum beer industry decline over the last 27 years by 80.5%.

1.3. PROJECT AIMS

According to the terms of reference (ToRs) for this project, eight-point specific objectives were to be addressed, and were as follows:

- Provide a general overview of the sorghum brewing industry in South Africa, its changes since 1989 and its projected change.
- Evaluate and document the generic industry processes
- Determine the water consumption and specific water intake
- Determine the wastewater generation and typical pollutant loads
- Determine local electricity, water and effluent prices and by-laws within which these industries function
- Critically evaluate the water (inclusive of wastewater) management processes adopted and provide recommendations
- Evaluate the industry adoption of the following concepts: cleaner production, water pinch, energy pinch, life cycle assessments, water footprints, and ISO 14 000 to name a few
- Provide recommendations for best practice.

1.4. SCOPE AND LIMITATIONS

The focus of this project was on industrial sorghum beer production, and excludes traditional beer brewing (home brewing). This is because of huge size of the traditional beer brewing and the lack of data related to resources management. Moreover, due to the large of traditional brewers across South Africa (exceeding 100 000 small entities), it was not possible to collect representative data on water, wastewater and energy management within the lifespan of this project. Sorghum beer industry in South Africa is dominated by one company, and therefore, it was not feasible to obtain data from diverse entities run by different owned companies for the purposes of obtaining heterogeneous data essential. Data from different companies offer valuable insights on resources management and environmental protection in a given industrial sector but this was not feasible within the traditional sorghum beer industry. The declining trend on the market share size and production capacity of sorghum beer industry in South Africa – also meant lack of investment in research and development regarding resources management (e.g. water, energy, etc.). Therefore, it limited the scope of the literature that can be reviewed for this specific industry unlike other beverage sectors such as malt beer, fruit drinks, and wine, among others.

1.5. METHODOLOGY

In this project, the methods used to solicit data are summarised in the following sections.

1.5.1. Literature review

Due to lack of research and development as highlighted in section 1.4, there was limited literature specific to the sorghum beer industry – not just in South Africa but globally concerning water, waste, energy, and wastewater management. The limited information available was used to offer insights on sorghum brewing industry evolution in terms of: (i) the number of plants, sales per annum, key sorghum brewing processes with respect to resources management (e.g. water, waste, etc.), etc., (ii) resources management (e.g. water, wastewater, etc.) practices aimed to protect the environment and promote sustainability, (iii) examining international case studies, if any, (perhaps adopted and viewed as best practices based on a defined criteria), and (iv) establishing likely trends in the next decade in the sorghum brewing industry based on the current data and projections.

1.5.2. Identification of sorghum brewing and malting plants

By means of internet search and interview with experts knowledgeable in the food and beverage industry as well as referrals aided to gain insights on the industry size.

1.5.3. Use of questionnaires, site visits, and interviews

At the beginning of the project a questionnaire was developed with anticipation that there were sizeable number of commercial sorghum beer brewing and malting plants in South Africa. This was based on the number of plants reported in the First Edition of Natsurv 5 of 1989 (Steffen, Robertson & Kirsten INC Consulting Engineers, 1989). However, it turned out that very few plants produces traditional commercial sorghum beer. As such, the questionnaire was used to conduct structured interview with an expert in this industry. Additional interviews were conducted in two of the brewing plants and one malting plant. Interviews at the plants were done with the technical personnel responsible to run the production plants. During the interviews key issues on water, energy and waste management were discussed. Accessible data was provided which formed the basis of the reported findings presented in this guideline.

2. PROCESS OVERVIEW: SORGHUM BEER BREWING

2.1. INTRODUCTION

Herein an overview of the sorghum brewing processes is presented. An understanding of the brewing processes informed the identification of best practices related to water, wastewater, waste, and energy management during different phases of beer production. To achieve this objective, the generic brewing processes for both traditional and industrial sorghum beer production methods are outlined.

2.2. TRADITIONAL BEER PRODUCTION PROCESS

The traditional or tribal method for producing sorghum beer is simple but varies significantly from one brewer to the other. This is due to variations in the malting procedure used, brewing times, and additional compounds added during the brewing phase, and geographical location. The brewing process ingredients includes but not limited to: water, maize mealie malt or sorghum malt, and yeast. The two main brewing processes are briefly outlined.

2.2.1. Malting

The malting phase consists of three processes, namely: steeping, germination and drying. During steeping, the sorghum grain is placed in a sack or a container which is permeable to water. The container is then placed in a body of water to steep the grain. The duration of steeping process varies among tribal brewers ranging from 16 to 40 hours (Dewar, Taylor, & Berjak, 1997). Germination entails spreading a layer of steeped grains on a mat, and then left for a period of time. The grains are either covered with leaves or another mat to accelerate the germination rate (Lyumugabe et al., 2010; Lyumugabe et al., 2012). Once adequate germination has been achieved, the grains are sun dried and prepared for brewing.

2.2.2. Brewing

The brewing process is initiated in a pot by boiling ground maize and then allow them to cool over 24 hours. Thereafter the boiled ground maize are diluted and boiled a second time over 2 to 3 hours before being cooled to room temperature. An equivalent amount of ground sorghum malt is added to the cooled maize and the mixture is allowed to stand for 24 hours. The mixture is then strained by means of finely woven reeds, and is ready for consumption within 3 days.

2.3. INDUSTRIAL BEER PRODUCTION METHODS

Production of sorghum beer at industrial scale is generally similar to the traditional production methods. However, the notable large variations in production methods for sorghum or opaque beers can be attributed to differences in taste, nature of process equipment used, and adjuncts added during the brewing process.

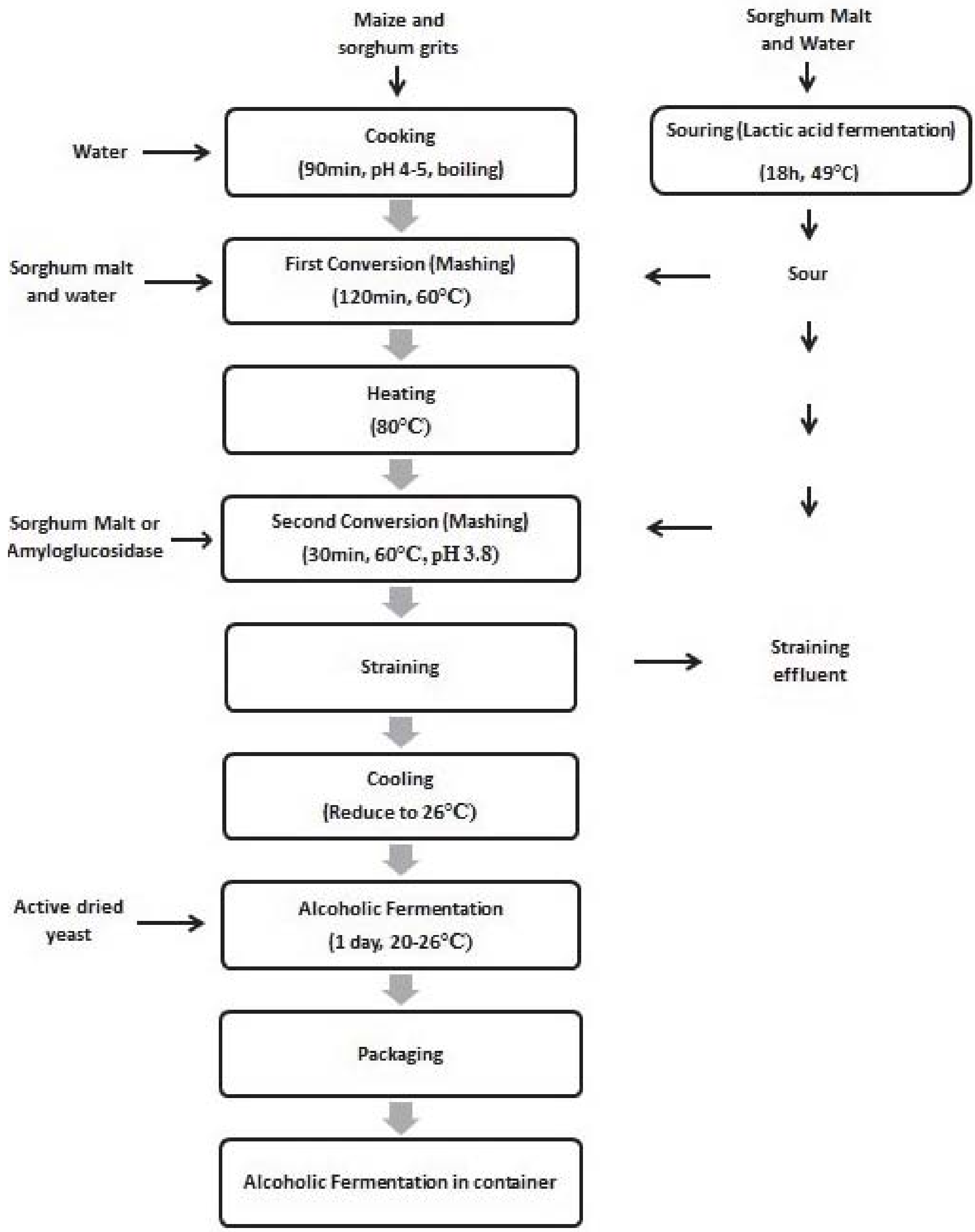

Figure 2.1: Generic industrial brewing processes for sorghum beer production (Taylor, 2004).

There are a number of industrial sorghum beer production methods with the split sour double cook method as mostly used (Taylor, 2004) as shown in Figure 2.1, and especially in Africa, including South Africa. Notably, the industrial production cycle of sorghum beer is shorter than that of malt beer brewing process. For example, sorghum beer does not undergo post processing such as filtration and pasteurization as is left to ferment in containers once the production ceases. In addition, sorghum beer does not require lengthy maturation phase after brewing is completed. Broadly sorghum beer production cycle consists of two main sections. The first section is the malting procedure consisting of the following processes, viz.: steeping, germination, and drying. Conversely, the second section entails the brewing procedure characterized by the following steps: souring, adjunct cooking, primary mashing, second adjunct cooking, secondary mashing, straining, cooling, and packaging.

2.3.1. Malting procedure

In South Africa two malting procedures are used, namely: Pneumatic and floor malting. In Pneumatic malting the sorghum grains are placed in a rectangular or circular chamber measuring up to 100 m long and 1.5 m deep (Taylor, 2004). Conversely, in the floor malting, the grains are processed on a concrete surface.

2.3.1.1. Steeping

Steeping process entails the immersion of sorghum grains in water to initiate the metabolic process generically regarded as germination. The steeping procedure not only initiates germination but also the water is used as a washing media for the grains. For instance, it removes dirt, chaff, and broken sorghum grains. Certain sorghum grains contain tannins that reduce sugar production of amylase enzymes. This is because tannins bind with the amylase enzymes. In cases where tannin rich sorghum variety are used in the malt, the steeping is normally done using dilute sodium hydroxide solution for neutralization purposes (Lyumugabe, Gros, & Nzungize, 2012).

2.3.1.2. Germination

During germination the seedlings are grown in a warm and water-saturated environment. Germination is either done using pneumatic or floor malting procedures. When Pneumatic procedure is used for the preparation of malt; the germinating grains rest above a slotted chamber through, and air is circulated using fans. Grains are then sprayed with water and rotated by means of helical screws at fixed intervals to ensure efficient air and water circulation. For the floor procedure the grains are spread out on a concrete surface of 10 to 30 cm deep and then watered by means of rain or a hose pipe. The grains are covered with shade cloth to reduce moisture loss and allowed to germinate under ambient environmental conditions. The grains are regularly circulated by means of rakes or spades (Taylor, 2004).

2.3.1.3. Drying

During the drying process the grains moisture content is reduced to *ca* 10%. In the Pneumatic procedure the sorghum grains are dried in a chamber similar to that used for grains germination. Warm and dry air is blown through the grains from below to reduce the grains moisture content. The temperature of the air used to dry the grains varies but do not exceed 50°C as higher temperatures can denature the useful enzymes, and in turn, reduce the amylase activity essential for grains fermentation. Conversely, for the floor malting procedure the grains are sun dried on a concrete surface and turned periodically (Steinkraus, 2004).

2.3.2. Brewing procedure

The processes that occur during the brewing procedure are outlined and discussed in this section. The split sour double cook method is initiated by means of the souring process.

2.3.2.1. Souring

The souring step is also known as lactic acid fermentation and is the initiating step for the brewing procedure. This process involves incubating 8-10% slurry of sorghum malt in water at fixed temperatures between 48-50°C for 48 hours. The lactic acid bacteria culture is maintained by means of back-slopping (Taylor, 2004).

2.3.2.2. Adjunct cooking

Adjunct cooking involves boiling maize slurry and grits for 1.5 to 3 hours at atmospheric pressure primarily to ensure the starch is gelatinized and solubilized. Shorter boiling times are also possible under pressurized boiling vessel conditions. To lower the mash pH to 4.5 – which is optimum for sorghum malt amylase activity – a portion of the sour is added to the maize and grits during the boiling procedure. This is followed by cooling the mash to 60°C using plate or tubular heat exchangers after the completion of the cooking process (Lyumugabe, Gros, & Nzungize, 2012).

2.3.2.3. Primary mashing

The mashing process is the conversion stage of the opaque beer brewing. Sorghum malt and water are added to the mash product from the adjunct cooking process. The conversion occurs at 60°C and lasts for approximately 1.5 hours. Mashing aims to solubilize and enzymatically hydrolyse the sorghum malt to create fermentable wort (Lyumugabe, Gros, & Nzungize, 2012).

2.3.2.4. Secondary cooking (heating)

The second portion of the sour is added to the product from the primary mashing process in order to further reduce the pH to as low as 3.8desirable for sorghum beer production. The entire mash and sour mixture are then re-cooked to ensure that all conversion malt and second sour added are completely gelatinized. The heating process is essentially the second cooking phase of the double cook method – greatly improves the brewing process efficiency (Taylor, 2004).

2.3.2.5. Secondary mashing

Second mashing follows the second cook process in order to obtain the desired viscosity of the sorghum beer, and lasts for 15 minutes at 60°C. The desired viscosity is achieved through adding small quantities of malt or amylase to the liquid slurry. (Taylor, 2004).

2.3.2.6. Straining

The spent grain and other macro particles (e.g. raw starch, insoluble proteins, fibre, etc.) are removed from the wort by means of straining. The mash is strained at high temperatures using high speed centrifugal decanters. A decanter is a process unit that aids the separation process by means of gravity. The wort is then invariably passed through a fine vibrating screen to remove coarse material of low density such as the malt pericarp that is not removed by the decanter (Steinkraus, 2004).

2.3.2.7. Cooling

The wort is then cooled to 30°C using heat exchangers and pitched with active dried yeast. The pitched wort is then either fermented in bulk or packaged for sale (Steinkraus, 2004).

2.3.2.8. Packaging

Packaging types and sizes vary as dictated by the consumer needs. For example, wort when fermented in bulk, the sorghum beer is packaged in 20 litres containers for draught sales. However, when the fermented wort is packaged directly after production normally the beer is packaged and sold in containers of either 1 or 2 litres. Containers are made of diverse materials such as cardboard cartons, low density polyethylene bottles, returnable high density polyethylene bottles, and drums. All containers with sorghum beer have slits at the top to allow carbon dioxide generated through active fermentation to escape (Taylor, 2004).

3. POLICIES, REGULATIONS, AND BYLAWS

3.1. INTRODUCTION

Post 1994, an increasing number of policies, regulations and by-laws have been developed and promulgated to govern various aspects related to water, energy and wastewater management. These instruments were developed in an attempt to promote equity and service provision to all South African citizens. These aspects are hinged on the National Constitution (RSA, 1996) in its Bill of Rights, particularly section 25 which affords all South African citizens the right to an environment that is not harmful to their health or well-being, and requires environmental protection through legislative instruments and other measures. Specifically, the Constitution upholds the principle of balancing pollution protection and ecological degradation, while promoting conservation in an endeavour to support security of sustainable development and use of natural resources while promoting justifiable socio-economic benefits such as water and energy. To operationalize this constitutional right several Acts, policies, and strategies which specify how human and environmental health can be assured have been developed. Herein, a number of policies, regulations and by-laws in the context of water and energy usage in the sorghum beer industry are presented.

3.2. WATER POLICY FRAMEWORK

3.2.1. National Water Acts

The Department of Water and Sanitation is the custodian of South Africa's water resources, and regulates the water sector by means of various Acts and strategies. Herein, a brief outline of the Acts and strategies with relevance to the sorghum beer industry are presented. The three key Acts that currently governs water use in South Africa, among others, are: (i) The National Water Act (NWA) (Act No. 36 of 1998), and (ii) The Water Services Act (WSA) (Act No. 108 of 1997), and National Environmental Management Act (NEMA) (Act No. 107 of 1998). NEMA will be presented in Section 3.5 as is the overarching regulation on environment – where water is viewed as one of environmental components.

The tenet of NWA addresses issues on the protection, use, development, conservation, management and control of South Africa's water resources. Of the Act primary focus is to: (i) promote equitable access to water, efficient, sustainable and beneficial use of water in the public interest; (ii) facilitate social and economic development, and; (iii) provide adequate water for the growing demand. To effect the implementation of the NWA, the Act stipulates the development of a National Water Strategy, and the formation of Water Management Areas where each area is managed by a Catchment Management Agency (CMA). The role of CMA is to manage water conservation and other aspects related to water resource management through implementation of catchment management strategies. Therefore, the CMA in certain jurisdictions with water shortages by law can enforce specific water conservation measures to the users including the sorghum beer industry.

The WSA deals with the rights of access to basic water supply and basic sanitation – with water conservation as the key objective. It provides municipalities with powers to enforce water conservation and demand management – which in turn impact on water users both the households as well as commercial and industrial entities. To achieve this objective, the Act outlines the establishment of implementing agents and their roles, namely the Water Service Authorities, Water Services Providers, Water Services Intermediaries, and Water Boards. The domestic sector constitutes the majority water users covered by the WSA. In addition, many industrial and commercial users are also provided water b municipalities. Under such case(s), the municipalities serve as both Water Service Authorities and Water Services Providers. As municipalities have powers concerning water conservation and demand management implies water users e.g. sorghum beer industry where inefficient water use can be demonstrated may attract steep penalties. Finally, WSA empowers the Minister to provide norms and standards as to the use of tariffs to promote water conservation – which directly imposes economic implications to the water users.

3.3. HEALTH AND SAFETY POLICY FRAMEWORK

Two Acts regulates aspects on health and safety aspects in the food and beverage industries. The National Department of Health regulates issues on food safety to ensure fitness for human consumption. In this sense, sorghum beer should meet threshold standard for human consumption, and therefore, should comply with the Foodstuffs, Cosmetics, and Disinfectants Act (FCDA) of 1972 (Act No. 54 of 1972; Amendment Act, No. 39 of 2007). The second Act focuses on the occupational and safety of workers and other persons outside of the work environment related to certain activities. The Department of Labour promulgated the Occupational Health and Safety Act (OHSA) of 1993 (No. 85 of 1993; Amendment Act, No. 181 of 1993) to safeguard the safety of workers and other persons. Chiefly, the OHSA aims to provide: (i) for the health and safety of persons at work as well as those who use plant and machinery, (ii) for the health and safety of persons other than persons at work against hazards to health and safety arising out of, or in connection with the activities of persons at work, and (iii) establish an advisory council for occupational health and safety.

3.4. TRADE AND LICENCING POLICY FRAMEWORK

Alcohol industry not only delivers economic benefits (e.g. revenue to the exchanger, employment, etc.) to society but also exerts inevitable varied degrees of social and economic costs. To establish national norms and standards aimed to maintain economic unity within the liquor industry; and address the undesirable economic impacts to society, the Department of Trade and Industry (DTI) promulgated the Liquor Act of 2003 (No. 59 of 2003). The Act has two-fold objectives. First, to reduce the socio-economic and other costs of alcohol abuse by means of: (i) setting essential national norms and standards in the liquor industry; (ii) regulating the manufacture and wholesale distribution of liquor; (iii) setting essential national norms and standards for the regulation of the retail sale and micro-manufacture of liquor; and (iv) providing for public participation in the consideration of applications for registration. And secondly, to promote the development of a responsible and sustainable liquor industry in a manner that facilitates: (i) entry of new participants into the industry; (ii) diversify of ownership in the industry; and (iii) ethos of social responsibility in the industry.

Moreover, the Constitution provides for the separation of powers between provincial and national governments. With specific reference to liquor licencing; this is a provincial government function according of Part A of Schedule 5 of the Constitution. To provide effect to this function, provincial governments have developed Liquor Acts and Liquor Policies within their respective areas of jurisdictions. Examples of such Acts and Policies are: the Gauteng Liquor Act, Act No 02 of 2003 (Gauteng Liquor Amendment Act 9 of 2003) and Kwazulu-Natal Liquor Licensing Act of 2010 (Act. No. 06 of 2010) – and similar Acts have been developed by other provincial governments across South Africa. Overall, both the national and provincial Acts and Policies applicable to govern the sorghum beer industry (from manufacturing to beer outlets) have caused unintended outcomes, for example, the closure of micro, and small and medium microenterprises (SMME). This is because of the conflict between the national and provincial legislations which make it onerous for small breweries to meet compliance requirements due to lack the resources.

3.5. ENVIRONMENTAL POLICY FRAMEWORK

The custodian of South Africa's environmental resources is the Department of Environmental Affairs (DEA), and the key Act that governs the protection of the environment is the National Environmental Management Act (NEMA) (Act No. 107 of 1998). The essence of NEMA is to protect the environment for the benefits of present and future generations. Water forms an integral part of these objectives since according to NEMA – is one of the environmental component, first, as a key natural resource that must be conserved, and secondly, as a resource that is essential for the preservation of both aquatic and non-aquatic ecosystems. Water also interacts with other environmental objectives around pollution prevention, for instance, in the sorghum beer industry water is used as a raw material and cleaning agent (to maintain non-ecological system). NEMA also promotes the adoption of integrated approach in an attempt to address complex and intertwined environmental issues through systematic identification and implementation of "best practicable environmental option(s)". Since equitable access to natural resources is enshrined in the Act, sorghum beer industry is not only compelled to conserve water but also treat wastewater to acceptable standards before release into the environment. And finally, ensure an efficient handling and management of solid waste streams to prevent possible environmental pollution.

3.6. BY-LAWS AND TARRIFS

By-laws are laws that are passed by the council of a municipality to regulate the affairs and services the municipality provides within its area of jurisdiction. The power by a municipality to pass a by-law is provided by the Constitution of the Republic of South Africa (Act 108 of 1996) which gives specified powers and competencies to local government. The traditional commercial sorghum beer industry as industrial user of water and sanitation services provided by the municipalities (Water Service Authorities and Providers) are governed by by-laws and tariffs, and which are municipality specific. Herein, by-laws and tariffs policies on water and sanitation services where the sorghum breweries operates are presented for the eThekwini and Tshwane municipalities by-laws and tariffs as illustrative examples.

3.6.1. City of Tshwane Municipality

The bylaws and tariffs on Water and Sanitation policies stipulates on how the Municipality charges commercial and industrial users, and the tariffs for sanitation are divided into three categories.

3.6.1.1. Normal Conveyance and treatment cost

This cost category covers the normal conveyance and treatment of wastewater whose quality equals to that of domestic wastewater, via a municipal sewer pipe system to wastewater treatment plant (WWTPs). It is calculated by multiplying the combined unit conveyance and treatment cost by the volume of wastewater discharged into the sewerage system, and industrial consumers pays for all wastewater discharged into the system.

3.6.1.2. Extraordinary Treatment Cost

In a case where the pollution loading (quality) of wastewater discharged into the Sewerage system exceeds the pollution loading of normal wastewater, then an additional treatment cost is charged calculated using the expression:

$$T_c = Q_c.\, t\left(0.6\frac{COD_c - COD_d}{COD_d} + 0.25\frac{P_c - P_d}{P_d} + 0.15\frac{N_c - N_d}{N_d}\right) \tag{1}$$

where: T_c = extraordinary cost to the consumer, Q_c = wastewater volume (Kl), t = unit treatment cost of wastewater (R/Kl), COD = chemical oxygen demand, COD_c = total COD in mg/l of wastewater including biodegradable and non-biodegradable, COD_d = total COD of domestic wastewater in mg/l, P_c = orthophosphate concentration of wastewater in mg phosphate/l, P_d = orthophosphate concentration of domestic wastewater in mg phosphate/l, N_c = ammonia concentration of wastewater in mg nitrogen/l, N_d = ammonia concentration of domestic wastewater in mg nitrogen/l, and for the 2014/15 FY, the parameters were set as follows: t = R 0.94 / Kl, COD_d = 710 mg/l, P_d = 10 mg/l, and N_d = 25 mg/l

3.6.1.3. Non-compliance with By-Law limits

In cases where the pollution loading (quality) limits exceeds the allowable limits, the charge is computed using the expression:

$$T_c = \frac{Q}{D.N\left[C_{AIP} - \frac{B_{LL}}{W_{PL}}\right].t_{NC}} \tag{2}$$

where: T_C = charge for non-compliance, Q = monthly volume in Kl, D = working days in the month, N = number of days exceeding by-law, C_{AIP} = average concentration of parameter exceeding bylaw, B_{LL} = bylaw limit, W_{PL}= Water Affairs standard limitation on parameter exceeding bylaw, and t_{NC} = tariff (set for R 0.65 / Kl).

3.6.2. eThekwini Municipality

The eThekwini Municipality has developed various policy frameworks that governs the discharge of trade effluent into the WWTPs. These policies includes the Water Services Development Plan (eThekwini Water and Sanitation Unit (EWS), 2013) and the Sewage Disposal Bylaws (EWS, undated). Acceptance of such effluent is subject to concentrations of certain substance being within stated limits; and dependent also on the treatment capacity of a given plant. A value of 25 ML/d is used as the capacity threshold for lower or higher treatment capacity (EWS, 2011). As a way of example, the effluent charges are determined based on two aspects the (i) volume-based charge, and (ii) volumetric and strength-based charge. Therefore, the total charge for the effluent is calculated using the expression:

$$T_c = V_c + V\left(\frac{COD}{360} - 1\right) + Z\left(\frac{SS}{9} - 1\right) \quad (3)$$

where T_C is the total discharge cost, COD is the total carbon oxygen demand, SS is settleable solids, V_c is the cost of trade effluent disposal based per kilolitre of trade effluent discharged, V as the rate for the treatment in the treatment works of standard domestic effluent having a prescribed COD value, and Z as the rate for the treatment in the treatment works of standard domestic effluent having a prescribed settleable solids value.

It should be noted that currently there are differences in the policies and by-laws governing liquor industry from province to province, and one municipality to another in terms of how effluent charges are determined. And secondly, in certain provinces, such by-laws and tariffs are missing, and the effluent from the sorghum beer production plants are being released into public wastewater treatment plants but with no charges levied. Therefore, to address these limitations, it is recommended that the by-laws should compel municipalities to measure every parameter in all samples, and the charges must be determined in the same way. Presently, companies operating production plants nationally have to deal with effluent charges on a case-by-case basis depending on the provincial jurisdiction where they have production operations.

3.7. CONCLUDING REMARKS

With the advent of South African Constitution post 1994, over the past 16 years numerous Acts and Amendments have been enacted and promulgated. In turn, this has an effect in terms of responsibilities to industries on the use of water and energy, and the management of wastewater from industrial processes aimed to protect the human health and the environment. For the liquor industry, Acts, Policies, By-laws and Tariffs have been formulated to regulate the industry to balance the economic benefits and the downside impacts of alcohol-related costs to the society. Although the extent of impacts due to Acts, Policies, By-laws and Tariffs may not be easily quantifiable tacitly but their effects cannot be ruled out as among the underlying causes of sorghum beer industry decline in South Africa.

Overall, conservation of water and energy; and pollution control has a critical role and significance in the modern traditional sorghum beer brewing industry. Conversely, the regulatory framework in the brewing industry extends beyond the production phase to other value chain phases including: distribution, labelling, packaging, advertising, trade and pricing practices as well as alcohol content. These aspects also play a role that has bearing to the survival for the sorghum beer industry – and it is within recognition, the sorghum beer has granted certain exceptions compared to wine or malt beer. This points to a clear need for systematic review on the impact of diverse regulatory and policy framework governing this industry, and compounded primarily by diversity of implementing departments and agencies. For example, given largely the low income market segment the sorghum beer seeks to service, high compliance costs has yielded unintended effects of impending the entrance of new players in the sector.

4. WATER USE AND MANAGEMENT

4.1. INTRODUCTION

Owing to differences associated with malting processes (1 industrial malting plant) and brewing processes (4 breweries) as of March 2016 in the sorghum beer industry in South Africa; databases for water consumption and quality of the water used are reported separately. This is to take into account the distinctive operational differences between the two types of plants categories as well as the indicators used to express the consumption of resources per unit of production. A similar approach was adopted in dealing with aspects on effluent generation, waste generation, and energy consumption reported in later chapters of this report.

4.2. WATER CONSUMPTION

Water is used in the sorghum beer industry for the malting of sorghum grains, beer brewing processes as well as cleaning and sanitization purposes. An outline of the brewing processes and where water is used has been outlined in Chapter 2, and therefore, will not be repeated here. The focus herein is to quantify water consumption in the commercial sorghum beer industry in South Africa.

4.2.1. Water consumption: brewing processes

Table 4.1 summarises water consumption data over eight months in four large commercial sorghum beer breweries in South Africa, and beer production over the same period (July 2015 to February 2016). The choice of the period was informed availability of data in all four plants. Data presented herein on water consumption is an aggregate for all processes where water is used (i.e. brewing, process, wash-down, bottle washing, boiling and cooling processes), and in accordance to the reporting water quantities norm followed in the industry. Using data for eight months as presented in Appendix A1 (Table A1.1), the estimated annual beer production and water consumption in the sorghum beer industry, respectively, were 214.3 million litres (L) and 759.5 million litres (L) (Table 4.1). This, in turn implies that, for every 1 litre of sorghum beer produced, 3.54 litres of water are used. All the water used in the breweries was from municipal sources, and the values presented are based on monthly water bills.

Table 4.1: Summary of water consumption and distribution in industrial brewing plants and beer produced.

Brewery		A	B	C	D
Beer produced* (L)	Monthly average	7 841 950	3 032 303	4 263 763	2 721 375
	Estimated annual	94 103 400	36 387 636	51 165 156	32 656 500
Water consumed* (L)	Monthly average	27 826 000	9 676 500	16 291 625	9 500 125
	Estimated annual	333 912 000	116 118 000	195 499 500	114 001 500

*Data used were from July 2015 to Feb 2016, and the computed monthly average values were used to estimate annual values for beer production and water consumption. All values are in litres.

Data on aggregated water usage per unit of beer produced are listed in Table 4.2 for eight months. Herein water consumption is expressed per 1000 litres of beer produced. The results suggest that water usage is closely related to the quantities of beer produced. For example, brewery A had the highest beer production per annum (Table 4.1) showed low specific water intake (SWI) from July to September (Table 4.2) under normal weather conditions. Brewery B is highly automated (mechanized) compared to other plants, and therefore, exhibited least variations of SWI. This suggests that the batch character of sorghum beer brewing process in addition to whether the plants are automated or manually operated influences water consumption.

And secondly, highest values of water consumption were observed from December to February, and likely partly due to weather conditions since these are the hottest months in South Africa. Hence, high rates of evaporation to a certain extent may have also contributed to increased water consumption per unit of production. This observation is supported by examining water usage data for June 2007 to February 2016 (data not reported here). Another possible contributing factor to higher water consumption in these months could be due to production was below each of the plant's designed capacity. Data presented in Table A1.1 (Appendix A1) suggest lower sorghum beer volume were produced in these months, and without a corresponding reduction in water usage.

Table 4.2: Water consumption in litres per 1000 litres of beer produced in sorghum beer brewing plants.

Month	Brewery (units: L/L)				Avg./month	SWI
	A	B	C	D		
Jul-2015	3 200	3 480	3 300	3 607	3 397	3.40
Aug-2015	3 191	3 516	3 451	3 300	3 364	3.36
Sep-2015	3 095	3 190	3 508	3 222	3 254	3.25
Oct-2015	3 430	3 218	4 253	3 244	3 536	3.54
Nov-2015	3 708	3 134	3 884	3 312	3 509	3.51
Dec-2015	3 753	2 967	3 213	3 909	3 461	3.46
Jan-2016	4 388	3 235	5 525	4 095	4 311	4.31
Feb-2016	3 800	2 809	4 063	3 388	3 515	3.51
Avg. (±Std)	3 571 ± 403	3 194 ± 221	3 900 ± 705	3 510 ± 309	3 544± 303	3.54 ±0.30

Avg.: Average, Std.: standard deviation

Overall, the SWI for individual breweries ranged from 2.80 L/L to 5.53. L/L (month to month), and, the overall aggregated SWI as 3.54 L/L (Table 4.2). The SWI values for the sorghum beer brewing industry category were deemed to be on the lower bound range of the published international values for malting brewing industry (most closely comparable industry). SWI for malt beer industry varies between 1 and 11 litres of water per 1 litre of beer produced (Perry and de Villiers, 2003; Braeken et al., 2004; Fillaudeau et al., 2006; Kanagachandran and Jayerantene, 2006). In comparison to the SWI average of 2.5 reported in Natsurv 5 of 1989 (Steffen, Robertson & Kirsten INC Consulting Engineers, 1989), the value obtained in this study is higher. Notably, the observed low variation of SWI values from one plant to the other, and month to month (Table 4.2) suggest that water management and accounting systems (in form of indicators) have been implemented to varying degrees. Moreover, with tightening legislative framework governing water usage due to scarcity in South Africa, and economic-driven factors such as steep market competition within the beer industry also act as other driving forces for the sorghum beer industry to implement water saving practices.

Since 2007, the Beverage Industry Environmental Roundtable (BIER, 2016) introduced the concept of water use ratio (WUR) as a broad indicator of how efficiently a facility uses water in various processes. The WUR is calculated based on water uses for all processes, for example, from the reception of raw materials to the packaged product (gate-in to gate-out). Since no specific values for sorghum beer industry are available for water or energy use ratio (EUR) in the BIER (2016) report, data in the beverage industrial category particularly the malt beer industry was used for comparison. The malt beer industry WUR for 2012 was on average 3.8 L/L, and in the range of 3.12-6.18 L/L based on data from 318 plants (BIER, 2016).

Results from this study indicates that water usage in the sorghum beer industry is on lower regime (3.2 L/L) of the international standards in the beer industry. Due to the limitation of companies that participated in the study (BIER, 2016), and the distinctive features of malt beer brewing processes from those of sorghum beer brewing processes, the comparison made here should be taken with caution, and only viewed as conditionally possible. This is because of marked differences in methods and underlying data used in BIER (2016), and in this study. Improved monitoring and evaluation of water utilization in the sorghum beer industry, values for 2016 (reported herein) in addition to targeted studies aimed to determine water use in various countries and zones can support to obtain representative values useful to set realistic benchmarks and target for the industry.

4.2.2. Water consumption: malting process

Water consumption for eight months in the malting plant are summarized in Table 4.3, and the malt produced over the same period. In the malting processes, water is used in the steeping and germination processes, and the rest is either incorporated into the product in this case sorghum malt (although very limited or rather negligible), or lost through evaporation and drying processes. Monthly water intake fluctuated between 5 004 000 to 6 706 000litres with an average of 5 939 750 litres. Data indicated that on average each kg of malt produced 7.85 litres of water were used, and ranged from 6.19 to 12.81 litres per kg. The total annual malt produced was 9 084 tonnes with monthly average of 757 tonnes. Therefore, annual water used in the malting processes was estimated to be 71.3million litres (71 277 000 L).

Data in Table 4.3 suggest that as production increased there was a reduction in water intake per unit of malt produced. For example, months (September to January) with highest production quantities of malt had corresponding lowest water intake per unit of product. In summary, using data on water consumption from malting and brewing processes the WUR required to produce 1 litre of sorghum beer was estimated. The annual estimates on water consumption in the malting plant and breweries were 71 277 000 L and 759 500 000 L, respectively, and sorghum beer produced as 214 300 000 L. Therefore, the estimated WUR was 3.88 L of water for every litre of sorghum beer produced.

Table 4.3: Water consumption during the malting processes over eight months.

Months	Malt Produced (ton)	Water intake (L)	Water intake (KL)	Water/malt (KL/ton)
Jul-2015	688.8	5 511 000	5 511	8.00
Aug-2015	750.9	6 652 000	6 652	8.86
Sep-2015	845.4	5 794 000	5 794	6.85
Oct-2015	900.4	6 554 000	6 554	7.28
Nov-2015	803.5	6 706 000	6 706	8.35
Dec-2015	758.5	5 004 000	5 004	6.60
Jan-2016	825.5	5 113 000	5 113	6.19
Feb-2016	482.9	6 184 000	6 184	12.81
Average	757.0	5 939 750	5 940	7.85
std. dev	128.21	686 150	68.60	2.10

*Kl: kilolitres; ton: tonnes, std. dev: standard deviation

4.3. WATER QUALITY

4.3.1. Water quality: brewing processes

Beer quality is dependent on the intake water quality used during the brewing purposes, and therefore, water from the supply sources should meet certain prescribed standards (set as allowable limits). Data on intake water quality were analysed for three months, and the results are summarized in Table A2.1 (in Appendix A2). For all breweries intake water was sourced from the municipality mains. Results suggested that breweries A and B water supplies from municipal mains met the prescribed specifications – irrespective of the minimum or maximum values recorded for any quality parameter over this period summarized in Appendix A2 (Table A2.1). Thus, the intake water did not require extensive treatment in order to meet the product(s) requirements – in this case different sorghum beer brands. In cases where the water quality parameter was outside specific limits, pre-treatment may be essential. This is because water chemistry (quality) outside the specified limits may not only influence the products taste but also the brewing efficacy. The required intake water quality is achieved through the removal of unwanted ions as well as addition of required levels of desirable ions to render the intake water of acceptable standard for intended purposes. However, none of the sorghum beer brewing plants pre-treats the incoming water before use in various processes.

Of note, in brewery B, of the total analysed intake water samples for the chlorides parameter; 67% of the total samples analysed were found to be below the lower set limit of 5 mg/L. For breweries C and D, of the intake water most tested parameters exceeded the maximum set limits as the supplying sources have harder water which in turn makes cleaning and sanitation processes be more water intensive compared to other plants. Herein few examples are outlined for illustrative purposes. In brewery C, the intake water chlorides concentrations were found to be above the maximum limit (50 mg/), for instance, in June and August of the total tested samples were 53% and 100%, respectively, exceeded the upper set limit. Similarly, the total dissolved solids (TDS) parameter was above the maximum set limit where the samples that exceeded those limits in July and August were 14% and 16%, respectively. For brewery D, except pH and chlorides parameters that were found to be within the set limits, the rest namely: total hardness, hardness due to calcium ions, and TDS to certain degree exceeded the set limits. For instance, TDS was above the set limits by 100%, 88%, and 86% for the samples analysed in the months of June, July and August, respectively (Table A2.1 in Appendix A2). Water quality data used in the malting processes was not available, and therefore, is not presented in this guideline.

5. WASTEWATER GENERATION AND MANAGEMENT

5.1. EFFLUENT GENERATION AND QUALITY: BREWING PROCESSES

5.1.1. Effluent generation

Effluent generated at different stages of sorghum beer brewing processes exhibit large variations in physical and chemical characteristics, and generally are process dependent. Results of effluent generation from the brewing processes are summarised in Table 5.1. Detailed information on data used for estimations are presented in Table A1.2 (in Appendix A1). Table 5.1 indicates average effluent generated from specific brewing plants ranged from 48.2% to 76.5% of the total intake water. The percentage of effluent generated from brewery B was the least, an indication that a plant producing different brands had higher water use efficiency, and secondly, highly mechanized plant operating at capacity translates to generation of lower industrial effluent from its operations. From the eight months data, the annual generated effluent for the sorghum beer brewing was estimated to 483.7 million litres – equivalent to 63.7% of its total water intake (759.5 million litres).

Thus the effluent generated for every 1000 L of sorghum beer produced was 2 257 L, and the specific effluent volume (SEV) was estimated as 2.26 L/L. A comparison of the SEV values of this study (2.26) and previous one reported in Natsurv 5 (Steffen, Robertson & Kirsten INC Consulting Engineers, 1989) (1.29) showed the average SEV has increased, and plausibly due to reduction on the number of large production plants over time which had a better usage of water, and in turn, low rate generation of effluent per litre of sorghum produced

Table 5.1: Summary of average effluent generation from sorghum brewing processes over eight months, and estimated annual volume.

Brewery		A	B	C	D
Beer produced (L)	Monthly average	7 841 950	3 032 303	4 263 763	2 721 375
	Estimated annual	94 103 400	36 387 636	51 165 156	32 656 500
Water consumed (L)	Monthly average	27 826 000	9 676 500	16 291 625	9 500 125
	Estimated annual	333 912 000	116 118 000	195 499 500	114 001 500
Effluent generated (L)	Monthly average	17 029 444	4 664 250	12 464 107	6 155 303
	Estimated annual	204 353 328	55 971 000	149 569 284	73 863 636
	Effluent %	61.2	48.2	76.5	64.8
	SEV	2.19	1.54	2.92	2.26

Data used were from July 2015 to Feb 2016, and average monthly values were used to estimate annual effluent generated. All values are in litres. SEV: specific effluent volume

5.1.2. Effluent quality

Wastewater physical and chemical characteristics play a significant role as indicators of how various streams should be managed before their release into the environment. In the sorghum beer industry, the characteristics continuously monitored and reported includes; pH, settling solids (SS), carbon oxygen demand (COD), oxygen absorption (OA), total solids (TS), conductivity, and total dissolved solids (TDS). Data solicited over three months showed the most frequently reported characteristics were pH, COD, TS, SS, and TDS, and the results are summarized in Table A2.1 (Appendix A2).

Data in Table A2.1 (Appendix A2) show that brewery A reported all five characteristics whilst C reported four with the exception of SS. For brewery B, COD was not reported, and TDS was only reported for one month (July). Brewery D had the least reported characteristics except for the month of July. Due to lack of consistent data in all the breweries it was not possible to estimate the specific pollutant loads (SPL) per brewery, and in turn, the entire sorghum beer industry. Moreover, reported COD on average in brewery A exceeded the set maximum limit of 2000 mg/L whereas for breweries C and D, TS exceeded several folds the upper set limit of 2%. Therefore, the high variability of effluent characteristics points to likely different methods required to treat the effluent before release into the environment.

Recently the sorghum beer industry begun to monitor the effluent biodegradable oxygen demand (BOD) parameter as one of key performance indicator on environment, health, and safety as per the requirement of Diego owned companies. Data available in this study was for a month and could not be used to estimate pollution load per annum. Adoption of consistent measurement of effluent quality from specific processes will offer insights on priority areas in order to reduce the pollution load.

5.1.3. Effluent pollutant load: brewing processes

The SPL was estimated with a month taken as a unit of time based on the effluent generated monthly. In this case, only three quality parameters with adequate data were considered, namely: SS, COD, and TDS. Data accessible was as an aggregate for the effluent generated from entire brewery and not for specific brewing processes. Hence, the SPL values presented are for the entire brewery and monthly average values. Due to high variation of brewing batch processes yields broad temporal effluent variations in composition. For example, effluent pollution load based on COD varied between 19 632 and 31 338 kg/month (with an average of 25 010 kg/month), and similar wide variations were observed for the settling solids and TDS (Table 5.2).

5.2. EFFLUENT GENERATION: MALTING PROCESS

Effluent generated from the malting plant was on average about 45.2% of the total water intake. Monthly effluent generated fluctuated from 1 710 000 to 3 230 000 L with an average of 2 684 000 L (Table 5.3). Thus, the annual effluent generated from the plant was 32 205 000 L. For every kg of sorghum malt processed, on average 3.55 litres of effluent were generated, and ranged from 3.45 to 3.60 litres per kg. The small variation in effluent generated per kg of malt processed suggest likelihood of well controlled production processes. No data was available for effluent characteristics generated from the malting plant, hence the SPL values could not be estimated.

Table 5.2: Summary of effluent quality parameters over three months from brewery A.

	Effluent (L)	pH	SS (mg/L)	COD (mg/L)	Total Solids %	TDS (mg/L)
Results limits	-	6-9	1-100	50-2500	0.2-2	200-2000
Jun-2014	15 102 812	3.65	8.35	2075	1.89	728
Jul-2014	11 060 508	4.44	4.83	1775	1.68	1515
Aug-2014	10 950 332	3.50	32.75	2215	1.90	1475
Max value	-	5.33	60.00	2530	1.50	1550
Min Value	-	3.20	4.50	1654	1.96	200
Average values	12 371 217	3.86	15	2022	1.82	1239
Jun-14 (PL: kg/month)			126.11	31 338		10 995
Jul-14 (PL: kg/month)			53.42	19 632		16 757
Aug-14 (PL: kg/month)			358.62	24 255		16 152
Pollutant load (kg/month)			189.40	25 010		15 332
SPL (kg/m^3) (overall)			0.02	3.01		1.85

*O-Absorption and conductivity parameters although were set at limits of 20-250 (units) and 300-2500, respectively, they were not recorded. PL: pollutant load, SS: settling solids, COD: chemical oxygen demand, TDS: total dissolved solids.

Table 5.3: Effluent generated from the malting processes over eight months.

Months	Malt Produced (ton)	Water intake (KL)	Effluent (KL)	Effluent /malt (KL/ton)	Effluent (%)
Jul-2015	688.8	5 511	2 470	3.59	44.8
Aug-2015	750.9	6 652	2 660	3.54	40.0
Sep-2015	845.4	5 794	3 040	3.60	52.5
Oct-2015	900.4	6 554	3 230	3.59	49.3
Nov-2015	803.5	6 706	2 850	3.55	42.5
Dec-2015	758.5	5 004	2 660	3.51	53.2
Jan-2016	825.5	5 113	2 850	3.45	55.7
Feb-2016	482.9	6 184	1 710	3.54	27.7
Average	757.0	5 940	2 684	3.55	45.2
std. dev	128.21	68.60	459	0.05	9.1

Std. dev.: standard deviation

The total effluent generated from the malting and brewing processes was used to determine the overall SEV for each litre of sorghum beer produced. Since the effluent generated from the malting plant and breweries were 32 205 000 L and 483 757 000 L, respectively, and sorghum beer produced as 214 300 000 L the overall SEV for entire process was determined as 2.41.

6. ENERGY CONSUMPTION AND WASTE GENERATION

6.1. INTRODUCTION

Sorghum beer brewing utilizes energy in different processes, and these include: heating, cooling, packaging, and transportation of raw materials and products within the production plants. Due to marked differences in final product(s) from the brewing plants (sorghum beer) and malting plant (malt), energy usage will be presented separately. Moreover, in this report, we adopt energy reporting in accordance to the current global trends where the results depict average total energy required to produce a unit of product; in this case one litre and one kilogram of sorghum beer and malt, respectively.

The energy consists of electricity from the national grid, coal, liquid petroleum gas (LPG), and diesel to meet varied production uses. Diesel is used to transport raw materials and packaged products in a plant (forklifts) and standby generators for power generation whilst the LPG is used for packaging beer in different containers. Electricity from the grid and power generated from coal (through steam generation) are used in a number of processes e.g. malting (steeping, germination, and drying), brewing, souring procedure (both primary and secondary cooking phases), cleaning and sanitation, and wort cooling procedure, among others. Data presented and discussed herein are for the entire plant (aggregated values), and not for specific processes.

6.2. ENERGY CONSUMPTION

6.2.1. Energy consumption: brewing processes

Table 6.1 summarizes energy consumption data for four large sorghum beer brewing plants in South Africa for eight months sourced from the national grid. Results presented herein expresses energy consumption per 1000 litres of beer produced in accordance to the reporting norm in the sorghum beer industry. On average the energy consumption for every 1000 litres of beer produced ranged from 39.57 to 88.45 KWh. Brewery B has the highest energy consumption per unit of beer produced. The high energy consumption in brewery B was not linked to operational practices but rather due to the brewery's design, its size, processes-layout design, and is highly automated transportation of raw materials (unlike in other brewing plants where transportation is done manually). Moreover, brewery B produces four types of sorghum beer brands as opposed to other brewing plants which produces either one or two brands.

According to an industry expert, acceptable energy consumption for sorghum beer production should be in the range of 32 to 88 kWh of electricity from the national grid per every 1000 litres of beer produced (Table 6.1). Hence, each brewing plant was deemed to be operating within the set limits. The estimated average energy consumption per 1000 litres of beer produced was 62.00 KWh, and in turn, the total annual energy demand from the national grid by the sorghum industry was estimated as 13.29 million KWh (13.29 GWh). Specific energy consumption (SEC) had a narrow range of between 0.058 and 0.070 KWh/1000 L with the overall SEC as 0.062 KWh/1000 L (Table 6.1).

Table 6.1: Energy consumption in sorghum beer industry for every 1000 litres of beer produced (KWh).

Month/Brewery	A	**B**	**C**	D	Average	SEC
Jul-2015	37.44	88.22	51.19	59.55	59.10	0.059
Aug-2015	36.16	87.31	57.02	54.06	58.64	0.059
Sep-2015	37.63	85.74	54.36	55.92	58.41	0.058
Oct-2015	39.09	89.32	59.84	55.44	60.92	0.061
Nov-2015	40.47	86.27	67.26	54.33	62.08	0.062
Dec-2015	39.16	88.52	57.51	64.85	62.51	0.063
Jan-2016	43.81	94.12	77.84	64.95	70.18	0.070
Feb-2016	42.77	88.1	54.68	70.99	64.14	0.064
Avg. (±Std.)	39.57 ± 2.50	88.45 ± 2.78	59.96 ± 9.05	60.01 ± 4.76	62.00 ± 4.09	0.062 ±0.004

Avg.: average; SEC: specific energy consumption

Regarding the total annual energy usage in the sorghum beer industry; the data indicate the industry is an insignificant electricity user in South Africa as it uses < 0.006% of the total energy generated by Eskom. For instance, the annual Eskom energy production was 217 903 GWh as of March 2013 to March 2014) (Eskom, 2014).

As mentioned earlier, a mix of energy sources are used to meet diverse production energy requirements in the sorghum beer industry. To estimate overall energy use in the sorghum beer industry (from malting to beer packaging) herein we adopt international emerging trends to account for the energy requirements in industrial processes. The shift leans towards estimation of energy use ratio (EUR) – a concept developed to account for total energy required to generate a unit of a product; in this case one litre of sorghum beer. Table 6.2 lists
estimated annual energy usage from different sources in the brewing plants. To estimate the EUR for a litre of sorghum beer, values in Table 6.2 were converted to a unit of energy (in this case in mega joules (MJ)). Adoption of same energy metric had two-fold merits. First, it allowed ease of comparison of energy usage with other beverage industries data (e.g. malt beer industry), and secondly, determine the contribution of each energy to the total energy needs in the sorghum beer industry. Conversion values used in this study are presented in Table 6.3.

Using results in Table 6.2 and conversion units listed in Table 6.3, the EUR for specific brewing plants were determined, and findings are shown in Table 6.4. Results indicate that EUR are unique for a given plant with brewery A having the lowest value, and brewery B the highest. EUR value for brewery C was not determined due to incomplete data as diesel data was not accessible. Similar to the comparison done for the WUR (in Chapter 5), the published malt beer industry data on energy consumption per unit of beer produced was used for comparison purposes. According to Beverage Industry Round Table (BIER, 2014) report, malt beer industry EUR for 2012 was 1.12MJ/L, and ranged from 0.80 MJ/L to 2.11 MJ/L based on data from 298 plants (BIER, 2016). EUR values for three sorghum beer brewing plants with complete data were found to be within this range; where the minimum and maximum values were 0.99 MJ/L and 1.76 MJ/L, respectively. Importantly, results in Table 6.4 indicate that coal is the dominant energy source in the sorghum beer industry as it accounts for 82% of the total energy usage followed by electricity from the national grid (16%), and the rest (diesel and LPG) accounts for about 2%.

Table 6.2: Different sources of energy and their respective quantities used in four breweries.

Brewery	Electricity (KWh)	LPG (tons)	Diesel (L)	Coal (tons)
A	3 708 180	11.38	46 866	3 224
B	3 217 095	1.57	13 203	2 145
C	3 024 375	38.84	NA	2 254
D	1 945 215	0.24	5 940	1 473
Total	11 894 865	52	66 009	9 096

NA: not available.

Table 6.3: Conversion of various energy units into joules

Energy source	Unit	Joules equivalent
Electricity (from grid)	KWh	3.6 MJ
Liquid petroleum gas (LPG)	L	26.7 MJ*
Coal	Kg	24.3 MJ
Diesel	L	38.1 MJ

*1 kg of LPG is equivalent to 1.96 L. Thus, 1 kg LPG ~ 52.3 MJ.

Table 6.4: Results of energy use ratio (EUR) for four brewing plants.

Brewery	Beer Produced (L)	Electricity (MJ)	LPG (MJ)	Diesel (MJ)	Coal (MJ)	EUR (MJ/L)
A	94 103 400	13 349 448	595 329	1 785 595	77 699 726	0.99
B	36 387 641	11 581 542	82 266	503 034	51 706 068	1.76
C	51 165 150	10 887 750	2 032 392	NA	54 315 375	-
D	32 656 500	7 002 774	12 560	226 314	35 499 300	1.31
Total	214 312 691	42 821 514	2 722 546	2 514 943	219 220 469	-

NA: not available, EUR: energy use ratio.

6.2.2. Energy consumption: malting plant processes

Energy sources as well as quantities consumed over eight months in the malting plant are listed in Table 6.5. Similarly, using conversion values in Table 6.3, the EUR for each kilogram of malt produced was 0.0295 MJ/kg with total energy required to produce 9 083.90 tons of malt estimated to be 267 854.67 MJ. No data in the malt beer industry was available for comparison since values reported in BIER (2014) were only for all brewing processes after the malting process (where the barley is processed before taken to the brewhouse for the malt beer production). In the malting plant, the most dominant energy sources is the diesel which accounts for about 90%, and 10% from coal. Electricity from the grid and LPG were found to be insignificant sources of energy in the malting processes.

Table 6.5: Distribution and quantity of energy from various sources used in the malting plant.

Month	Malt Produced (Tons)	Grid Electricity (KWh)	LPG (Tons)	Diesel/Gas Oil (Litre)	Coal (Tons)
Jul-15	688.80	20.88	0.02	889.40	83.00
Aug-15	750.90	20.45	0.02	412.30	84.76
Sep-15	845.43	22.42	0.02	495.20	90.14
Oct-15	900.40	25.46	0.02	371.80	112.00
Nov-15	803.50	24.07	0.02	350.50	121.48
Dec-15	758.50	22.62	0.02	310.30	91.24
Jan-16	825.50	20.65	0.02	1132.90	76.64
Feb-16	482.90	20.37	0.02	259.00	44.00
Monthly average	756.99	22.11	0.02	527.68	87.91
Annual values	9 083.90	265.35	0.24	6 332.10	1 054.89
Energy equivalent (MJ)		955.28	12.55	241 253.01	25 633.83

Notably, as more energy data is collected annually, in future, it will be plausible in the sorghum beer industry to determine the energy required to produce a litre of beer starting from malting processes to the brewing processes after the beer has been packaged ready for transportation to the distribution points and/or retailer outlets. In addition, data collection should consider energy consumption used in transporting malt from the production malting plant to the four brewing plants. These endeavours will aid the sorghum beer industry to account for the energy consumption over the entire value chain. In turn, the generated information will be useful to identify processes or areas with very high energy consumption, and hence, develop targeted alternative approaches aimed to yield benefits such as the reduction of energy costs, protection of the environment, among others without compromising the product quality or utility services.

6.3. WASTE GENERATION

Sorghum beer industry utilizes agricultural inputs as feedstock (sorghum grains), and therefore, inevitable waste streams are generated. This is because not all parts of the sorghum cereal are incorporated into the final product – the sorghum beer. Sorghum breweries generate waste streams which consists of spent grains a by-product), coal ash from the boilers, and residues (regarded as “maroek”) from the effluent after the straining process. Spent grain is sold as a by-product to farmers. Other non-organic solid waste streams (regarded herein as general waste) generated are broken bottles, paper, caps, and cardboards. In this guideline, similar to water and energy consumption aspects, solid waste data for the brewing and malting processes will be presented separately.

6.3.1. Waste generation: brewing processes

Table 6.6 lists different forms of solid wastes generated at various stages of the sorghum beer brewing cycle, and in turn, estimates of specific wastes per unit litre of beer produced. Results suggest that two approaches are currently in place (data presented in Table A1.3, Appendix A1) to manage the solid waste. Solid wastes with high organic content are by-products in this case spent grain; and hence, are separated and/or recovered and sold to farmers as feedstock for livestock. This has an additional benefit of reducing the total COD (or in other cases measured as BOD in the effluent). It should be noted that a reduction in COD, in turn, reduces monthly effluent charges levied by the municipalities in accordance to the billing formulae presented in Chapter 3.

Table 6.6: Waste generation per 1000 L of beer produced from different streams.

Brewery	Beer produced (L)	Spent grain (tons)	Maroek (tons)	Coal ash (tons)	Spent grain per 1000 L beer (kg)	Maroek per 1000 L beer (kg)	Coal ash per 1000 L beer (kg)
A	94 103 400	6 829.08	875.11	818.91	72.57[+]	9.31	8.70
B	36 387 641	2 520.74	516.15	544.95	69.24	28.40	14.99
C	51 165 150	4 622.10	673.40	572.45	90.59	13.64	11.19
D	32 656 500	1 697.76	391.88	374.14	51.83	12.00[++]	11.50
Total	214 312 691	15 669.68	2 456.54	2 310.45	-	-	-
Average	-	-	-	-	73.12	11.46	10.78

[+]values were calculated based on estimated quantities of spent grain as actual data were not available. Using data for brewery A from 2007to 2015, average spent grain per hectolitre of sorghum beer was estimated as 0.007257 tons/ hl.
[++]An estimated quantity of “maroek” produced as actual values were not available for brewery D. Using data for breweries A to C, average “maroek” per hectolitre of sorghum beer produced was estimated to be 0.0012 tons/hl.

On average the wet spent grain generated monthly ranged between 51.83 and 90.59 kg for every 1000 litres of beer produced for each brewery with an overall average of 73.12 kg/1000 L of beer. Hence, the total wet spent grain from sorghum beer industry was estimated as 15 669.68 tons per annum. In the First Edition of Natsurv 5 of 1989 it was reported that for every 1 000 L of beer produced 105 kg of wet spent grain were generated (Steffen, Robertson & Kirsten INC Consulting Engineers, 1989). Therefore, current wet spent grain generated for every 1000 L of beer produced was approximately 69.6% of 1989 value. Also, average coal ash and maroek generated per 1000 L of beer produced were estimated as 11.46 kg and 10.78 kg, respectively.

In First Edition of 1989, the coal ash and maroek waste streams were not reported, and therefore, values in this guideline could serve as base statistics for future studies. In addition, following the acquisition of 50% equity interest in UNB traditional sorghum beer business by Diego (Diego 2013), reporting of waste generation has been instituted to include all forms of waste streams generated. Presently landfilling is used to dispose of maroek and coal ash. According to NEMA (Act No. 107 of 1998) waste classification coal ash is classified as hazardous, and therefore, is disposed of as hazardous waste using specialist contractor in order to meet legislative requirements.

6.3.2. Waste generation: malting process

Malt production is also accompanied by generation of waste streams and by-products as shown in Table 6.7.

Table 6.7: Waste generation per ton of malt produced for different forms of waste streams.

Month	Malt Produced (Tons)	Spent grain (Tons)	Landfill: coal ash (Tons)	Landfill: other wastes (Tons)	Spent grain /malt (kg/Ton)	Coal ash to landfill/malt (kg/Ton)	Other wastes to landfill/malt (kg/Ton)
Jul-15	688.8	5.76	21.08	56.92	8.36	30.61	82.63
Aug-15	750.9	8.53	21.53	14.47	11.36	28.67	19.27
Sep-15	845.43	23.21	22.90	103.10	27.45	27.08	121.96
Oct-15	900.4	21.03	28.45	205.55	23.36	31.59	228.29
Nov-15	803.5	16.99	30.86	221.14	21.14	38.40	275.23
Dec-15	758.5	13.20	23.17	114.83	17.40	30.55	151.38
Jan-16	825.5	15.57	19.47	106.53	18.86	23.58	129.05
Feb-16	482.9	55.08*	11.18	24.82	114.06*	23.14	51.41
M. avg.	756.99	14.80	22.33	105.92	18.28	29.20	132.40
An. est.	9 083.90	178.68	267.94	1 271.06	219.33	350.45	1 588.83
An. avg.					24.14	29.50	139.92

M. avg: monthly average; An. est: annual estimates; An. avg: annual average, *value for February 2016 was excluded in determining the monthly and annul average values.

The average wet spent grain generated monthly were between 5.8 and 23.2 kg per ton of malt produced (with average of 14.8 kg per ton). Hence, the estimated total wet spent grain from the malting plant was 178.7 tons per annum. Also, average coal ash and other waste streams generated per ton of malt produced were estimated as 18.3 kg and 132.4 kg, respectively. Thus, the total waste sent to the landfill were estimated as 1 939 tons per annum with coal ash and other forms of wastes accounting for 18.1% and 81.9% (by weight), respectively.

7. BEST PRACTICES FOR WATER USE AND WASTEWATER MANAGEMENT

7.1. WATER USE AND WASTEWATER MANAGEMENT: PREAMBLE

Adoption of best practices in a specific industry category on water use and wastewater management is influenced by defining features such as: product type, category (class in this case food and drink industry), size, geographical locality of the processing plants, manual or automated operating systems, water and effluent treatment costs, and regulatory requirements. Sorghum beer brewing industry uses water as process raw material and in other purposes like cooling, cleaning, and sanitation. Currently operating sorghum beer breweries were developed few decades ago, and therefore, best water uses and wastewater management are likely achievable through retro-fitting- and management-oriented approaches as opposed to adoption of design-oriented options. The later approaches incorporates cleaner production practices at design phase to optimise resources utilization, and reduce utility costs for the production plant in question.

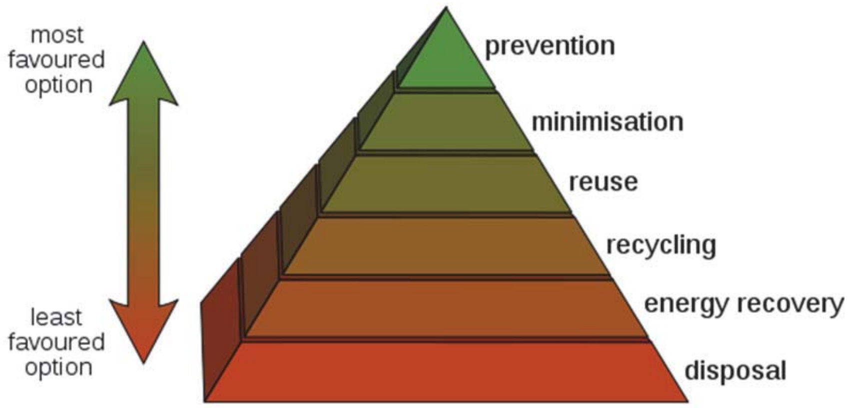

Figure 7.1: Waste management hierarchy based on Pollution Prevention Act (US Congress, 1990).

During data collection phase to develop this guideline, it became apparent that targeted water use was considered a strategic economic tool for cost reduction by the industrial sorghum beer industry. This cost-cutting measure was partly to address the steep market competition within the beer industry in South Africa's market – which in general is in disfavour of the sorghum beer as outlined in Chapter 1. Herein, the best practices either observed to be currently in use in the industry, or deemed can improve further water conservation are presented. The best practices on water use are hinged on waste management hierarchy principles pictorially depicted in Figure 7.1.

In principle, approaches adopted to manage water use in the sorghum beer industry should promote: prevention, control, minimisation and recycling to the extent possible without compromising the hygienic standards, and at reasonable cost. Therefore, cleaning and sanitation processes should be optimized to reduce: (i) water costs associated with direct billing by municipalities, (ii) use of cleaning chemicals, (iii) energy consumption, and (iv) wastewater treatment charges. Therefore, best practices adopted should aid a given brewery to reduce water consumption, optimize water use, and also ensure sufficient water of required quality. Approaches that can yield improved water use were broadly categorised as technology-based; operational practices-based; and reuse-, recovery- and recycling-based. Each of these aspects are summarised in the following sub-sections.

7.1.1. Technology-based approaches

Water consumption is dependent on the type of equipment used and the layout of various unit operations in a given plant. Thus, water usage can be prevented or minimized by the following approaches from a technological viewpoint:

1. Installation of flow meters to monitor water flows per unit of operation or certain supply lines. Data collected is useful in evaluating and developing water balance in a given plant; and other benefits

includes identification of: (i) water leaks; (ii) incorrectly set, poorly maintained and/or malfunctioning equipment; (iii) redundant lines; and (iv) unauthorized usage or discharge of clean water; and/or (v) likely discharges of clean water to effluent streams. Merit: easy to install and monitor, aids to identify areas and processes where water is used and by how much, likely sources of effluent and associated quantities, and identification of large water users within a brewery or maltster. And finally, yields data over time essential for targeting water usage per given area or unit operation (process).

2. Installation of Clean-in-Place (CIPs) systems to decontaminate equipment. Offer benefits through, first, reduction of water, cleaning chemicals, and energy consumption; secondly, improves product and/or by-products recovery; thirdly, aids production planning and scheduling to reduce the number of cleaning cycles, and finally, the recovery of cleaning chemicals, and water for re-use (Box 1).

> ***Box 1: Best practice***
>
> *Brewery A uses CIPs systems where the cleaning solution is recycled a number of times, steam injectors are used to control the CIP system, and the solution is kept at a temperature of 50°C to derive optimal benefits.*

> ***Box 2: Best practice***
>
> *Many cleaning pipes were fitted with auto-taps to prevent loss of water when a given cleaning cycle is completed. Use of high pressure-low volume hoses was observed in several breweries and the malting plant.*

3. e
nt of low efficient cleaning equipment (e.g. hosepipes) with high pressure-low volume hoses to reduce water and chemical usage (Box 2).
4. Installation and use of high-pressure rotary nozzles inside tanks to ease cleaning process, and reduce water consumption.
5. Installation of pigging system(s) in product and by-products transfer lines to improve product and by-products recovery; that in turn, reduces water usage for cleaning purposes, and indirectly reduces the effluent load. Such systems have been installed in Brewery A.
6. Fix-flow restrictors in taps and other water fixtures to avoid or minimize water wastage after completion of a given activity (see Box 2).
7. Use of modern dosing cleaning systems as they reduce quantities of cleaning chemicals, and in turn, reduce the pollution load of non-organic pollutants in the wastewater.

7.1.2. Operational practices-based approaches

In the food and beverage industry operational practices generally exhibits procedural, administrative, and institutional culture characteristics. Hence, they are generically regarded as good housekeeping practices, and normally require low levels of investment. Operational approaches include:

1. To train personnel to view water, chemicals, and wastewater as valuable resources, as well as achieve attitude change. The overall goal is to improve how raw materials and utilities are effectively handled (Box 3 on examples relate do personnel training).

> ***Box 3: Training of personnel***
>
> - *Basics on waste, chemicals, and water management practices.*
> - *How to identify faulty, inefficient process operation(s), and leakages/breakages.*
> - *How to carry out maintenance and repairs operations as per schedule without delays.*
> - *Approaches to save or reduce water use during cleaning/washing processes.*
> - *How to treat effluent streams and associated undesirable consequences of dumping hazardous substances in drains without prior effective pre-treatment.*
> - *Value of diverse set of raw materials, cleaning agents, and water as production resources, and hence the need for effective and efficient use.*
> - *How to carry out emergency and clean up procedures as well as on how to communicate and report such incidences e.g. chemical spills or accidents.*

2. Regular inspection of piping system to detect leaks to allow timely repairs, and replacement where necessary.
3. Develop strategies to reduce magnitude and frequency of spillages and leakages of intermediate products and sorghum beer from pipes and equipment. Minimises the number of cleaning cycles, and in turn, quantities of wastewater generated. Use of adsorbents to clean-up spills and leaks immediately to reduce demand for cleaning freshwater, and organic loading in wastewater stream. Where appropriate (as far as practically possible) the first cleaning cycle in cases of spills and leaks recycled water should be used.
4. Optimize the batch operations through effective scheduling of production processes to reduce cleaning sessions. Conserves water, chemical usage, and quantities of wastewater generated.
5. Ensure all taps are closed when not in use to conserve water.
6. Segregate various streams (e.g. from cooling systems, boilers, general cleaning, ion exchange operations, etc.) to enhance water and cleaning chemical recovery.
7. Schedule periodical maintenance and repairs of process equipment, pumps, and compressors. This minimises cleaning cycles, loss of products and by-products through leakages to waste streams, prevents organic loading to wastewater, and avoids inefficient operations.
8. Use mechanical techniques to remove organic sources in equipment and surfaces before cleaning and sanitation processes begins to reduce water and chemical consumption, reduce quantity of wastewater generated, and reduce organic loading in the wastewater. Any example to achieve this is by use of compressed air or brooms to clean the equipment and surfaces.
9. Apply counter cleaning technique during cleaning sessions to minimize the quantities of water required per cleaning cycle.
10. Adopt a policy on immediate cleaning of equipment and surfaces after each operation to reduce cleaning water demand, quantities of wastewater generated, and cleaning chemicals demand.

7.1.3. Reuse-, recovery- and recycling-based approaches

Reuse, recovery, and recycling based approaches can contribute towards reducing water usage in the sorghum beer industry, and are driven by the nature of products and intermediate by-products during sorghum beer manufacturing process. The recovered by-products are generally not reusable in the same process but as raw materials in other processes and/or industries. And secondly, high and stringent requirements for food and beverage industry for the purposes of protecting consumers' health render process by-products and recycle wastes not easily reusable in the process(es) due to risks and uncertainties associated with microbial contamination (Box 4 for case example of recovery and re-use in different industry).

Box 4: Case of waste not a drop project: Namibia Brewery

In 1997, the Namibian Breweries opened a new sorghum beer facility in the inland desert of Namibia, and also adopted a new principle: "good beer, no chemicals, no pollution, more sales and more jobs." Working with an array of specialists, the brewery embedded itself in a complex of projects that were designed to feed off of each other's waste products, imitating natural materials cycles. Spent grain from the brewing process is used to raise mushrooms (400 kg per week) and pigs (120 per year) for food. The pig manure is then sent to a digester to produce methane, which serves as a substitute for firewood. The return of investment of US$400,000 and additional systems was achieved in four years. Cited from: Tangri (2003).

Among the approaches that can reduce water consumption under this category includes:

1. Reuse of cleaning keg washing water after chemical precipitation and sedimentation as this yields reduction in water use and cleaning chemicals.
2. Recovery of spent grains for use as livestock feeds using sieves. Recovered spent grain are sold as by-products.
3. Reuse of final rinse-water for pre-rinse stage.

7.2. WATER MANAGEMENT TOOLS AND APPROACHES

To improve water use in sorghum beer breweries, herein several tools are presented that can aid to: (i) identify areas of high water use and/or loss, (ii) quantify the ratio of water used to the throughput, (iii) address current and anticipated legislative compliance requirements, and (iv) mitigate the issue of increasing water scarcity especially in breweries located in large metropolitan municipalities. The tools and approaches in the context of sorghum beer industry are briefly outlined, and examples of application and associated benefits in brewing industry are provided.

7.2.1. Water pinch analysis

Water pinch analysis tool offer insights on how water is used in different processes with a goal to reduce the environmental impacts associated with water use. In the sorghum beer industry, there was no evidence on the application of water pinch analysis in the published literature, nor during data collection phase. Due to distinctive water quality requirements for specific uses in a sorghum beer brewery – dependent on the concentrations of contaminants – water pinch analysis can offer the industry a number of benefits. These benefits consist of reducing demand for freshwater (e.g. in cleaning and cooling purposes), and in turn, reduce (i) volumes of wastewater generated that would require treatment,(ii) energy and chemicals costs (where for example, hot water streams can be used for cleaning without the need for cleaning chemicals), and (iii) wastewater treatment costs in the municipal treatment plants.

Importantly, because each of the four sorghum beer breweries and the maltster have unique design layout and modifications over the years, it would be recommended to conduct pinch analysis for each plant to establish where optimal benefits are feasible and cost effective. Available literature suggest that water pinch can yield benefits in terms of reduction in water consumption and wastewater generated as well as energy conservation (Tokos and Pintaric, 2009; Tokos and Pintaric, 2012; Tokos et al., 2012).

7.2.2. Water footprinting

Water footprinting (WF) is a concept and methodology developed to promote water stewardship. Results of WF are area and/or process of focus dependent where the applications of results are context specific and generalization may yield misleading inferences. For sorghum beer production; water footprinting can assess water use in three areas, viz.: (i) agricultural production of sorghum cereals, (ii) industrial production of beer, and (iii) combination of (i) and (ii). Application of water footprinting in the sorghum beer industry from farm to the beer packaging phase could not be established during data collection or published literature.

Thus, in future endeavours to improve water use, it is recommended that WF tool be considered for application in the sorghum industry (similar case has been done on malt beer (see Box 5) to optimize water use across the entire value chain. Among the merits of this approach are systematic determination of a company's or more specifically a given brewery's or maltster's water use, serves as a standard tool to undertake informed comparison between various plants, benchmark or set target for water consumption per unit of beer produced across, for example, various sorghum beer brands, ensure long-secure supply of sorghum cereals as raw material, manage increasing water supply-related risks (linked to increasing water scarcity occasioned by draughts, competition among users), and improve water management within the entire sorghum beer supply chain (from farm to the gate from the production breweries).

Box 5: Case of water footprinting studies in malt beer industry

A water footprinting tool application was done in beer brewing industry by SABMiller. The amount of water used in malt production, container manufacturing, and barley growing were determined with 95-98% of the organisation's water footprint lied within agricultural production – where about 155 litres of water are required for every litre of SABMiller beer produces (SABMiller and WWF Report, 2009).

7.2.3. Life cycle assessment

Life cycle assessment (LCA) is a methodology that can aid companies to assess environmental attributes of their product and services. Furthermore, LCA is hinged on cleaner production (CP) concepts, for example, the reduction and efficient use of raw materials (e.g. through recovery, recycling or reuse), and pollution prevention through source reduction approaches. LCA starts from the acquisition phase of raw materials (in this case sorghum cereals) to the disposal stages of various waste streams. Performing an environmental assessment, therefore, aids to identify and reduce environmental impacts and consequent liabilities, and in turn, save costs and likely liabilities arising from environmental pollution. No case studies of LCA application in the sorghum beer industry were found in the published literature. Notably, numerous LCA case studies have been published in closely related industry: the malt beer industry (Mata and Costa, 2001; Koroneos et al., 2005).

The benefits of LCA outcomes to companies have been demonstrated through systematic adoption of green-environmental practices, and among them are: (i) meeting customers' needs, (ii) enhanced protection of the environmental protection, (iii) costs reduction through better utilization of resources (e.g. energy, raw materials, water, labour, transportation, etc.), and (iv) ability to improve corporate trust and reputation by customers, that in turn, has spin-offs like increased market competitiveness. For the sorghum beer industry to conduct LCA in their processes requires setting of realistic timelines to solicit data on agricultural sorghum production, industrial beer production (integrating malting and brewing processes data), storage, and distribution, packaging, consumption and waste management. Through smart and systematic approaches where studies are conducted per given process or processes may aid the industry to develop well-curated databases to support holistic LCA in the industry.

7.3. VALUE CHAIN ENVIRONMENTAL RESPONSIBILITY APPROACH

Most prevalent approaches by industry including the sorghum beer industry is to focus their environmental footprints from gate-in (raw materials and utilities) to gate-out (products and by-products), and often in treatment of waste streams to comply with regulatory and by-laws stringent requirements. To gain a better understanding of the environmental impacts of the sorghum beer industry, there is need to consider impacts across value chain from the farms (sorghum growing) through the malting and brewing processes to the bottle stores which are outlets of sorghum beer to the customers.

As recently highlighted for the malt brewing industries to consider the environmental impacts over the entire value chain (Olajire, 2012), similarly; there is need for the sorghum beer industry to be cognizance of their operations' environmental impact across the entire value chain. This means, the urgency to identify high priority areas that exerts highest environmental impacts whether in terms of water, energy, chemicals, waste, etc. and find mechanisms to minimize or eliminate such processes that induces undesirable effects.

One way to implement this approach is to establish total value chain inventory where the current databases (reported in this guideline) may serve as the base, and then are incrementally extended to other stages of the value chain. For example, it will aid to accurately account water use per every litre of sorghum beer produced from the farm through the malting and brewing phases to the bottle store outlets where the sorghum beer is sold to the customers. Such approach will offer the sorghum beer industry unique opportunities to address associated environmental impacts e.g. by purchasing cleaning chemicals with minimal environmental impacts (see Box 6), support famers to create new varieties of sorghum with better yields, and reduce water demand though targeted research and development initiatives.

Box 6: Approaches to address chemicals management** (**Musee et al., 2007)

- *Recycle cleaning agents before they are sent for their recovery (on/off site).*
- *Reuse of the cleaning solutions till they are saturated (avoid once through use).*
- *Ensure correct chemical concentrations for cleaning and process chemicals by measuring the quantities before use*
- *Segregate chemicals which are incompatible to avoid explosions and contamination during usage and storage periods.*
- *Limit the quantities and inventories of chemicals purchased to control wastage via expiry (use the thumb rule first in, first out) or misuse.*
- *Use de-ionized water for preparing cleaning solutions to minimise quantities of chemicals used due to water hardness.*
- *Pump fixed amount of cleaning/sanitizing solutions to equipment and surfaces to reduce overall chemical consumption.*

Therefore, with data, synergistic benefits of using different tools and methodologies described in sections 7.2.1 to 7.2.3 will be feasible. Following recent acquisition of UNB by Diego, there is a shift towards implementation of resources management audit throughout the value chain, and the focus on environmental, health, safety, and regulatory compliance has begun to receive increasing attention. For example, sorghum beer industry in South Africa recently undertook a process of auditing all their activities and resources, for example, in relation to their likely impacts in all plants (malting and brewing). The data is envisaged to will serve as base for future routine reporting requirements. The auditing and reporting was undertaken in accordance to the performance and key metrics set by Diego in all the company's operations (Diego 2013).

8. CONCLUSIONS & RECOMMENDATIONS

8.1. CONCLUSIONS

Based on different indicators whether in terms of resources consumption, annual beer production, and the number of manufacturing both malting and brewing processes, it is evident that the size of the industry in South Africa has declined over the last two decades.

Most of the resource based values for the water intake per unit volume have not changed considerably. This is likely due to tight control exercised as water and energy conservation are viewed as strategic approaches to address steep market competition in the beer industry, and in addition, comply with tightening environmental-, safety-, and health-related legislative framework.

Very limited research, if any, has been done in the sorghum beer industry on how resources consumption such as water and energy can be optimised using various types of principles, tools and methodologies such as cleaner production, waste minimization, life cycle assessment, water footprinting, and pitch technology, and

For the sorghum beer industry to become more competitive, there is need to re-examine resources management practices with a view to improve the processes efficiency and effectiveness.

8.2. RECOMMENDATIONS

Home sorghum beer brewing industry accounts over two-thirds of the sorghum beer sector in South Africa. This has significant implications on the use of resources such as water, energy, raw materials as well as management of wastewater and solid wastes. For example, discharges from numerous entities over large geographical areas in South Africa are likely to exert adverse effects to diverse sensitive ecological systems. To date, there is lack of scientific literature and technical reports on the utilization of resources (e.g. water, energy, etc.) and likely associated impacts to the environment and communities related to home brewing entities.

For each of different aspects on water, energy, chemicals, and waste management – a number of best practices have been identified and proposed. It is therefore recommended that each of the practices be carefully considered within the context of specific plants, and implemented accordingly where feasible.

Data is key in supporting useful assessment of environmental resource management impacts of a given industry starting from the production of the raw materials, to the beneficial use of process by-products, and finally responsible disposal of waste streams in compliance to specific legislative requirements. Thus, it is recommended that sorghum beer industry should consider to examine its impacts over the entire value chain using tools such as water footprinting and life cycle assessment. Information generated will offer valuable insights on the overall impacts of the industry to the environment, and in turn, develop targeted interventions to specific phases of the value chain where further improvements are practically possible, and can yield meaningful outcomes.

To increase research aimed to generate data essential to support effective resources management in the sorghum beer industry, we recommend that such projects should be considered for funding from statutory levies administered by the Sorghum Trust. This has the benefit of increasing the industry's competitiveness besides enhancing its social responsibility to communities where it operates. Moreover, it has the benefit of capturing data on specific water catchment areas and unique ecological systems to aid the industry to understand potential risks, impacts and opportunities which can be addressed through well-tailored interventions.

REFERENCES

A&T CONSULTING and ECKART NAUMANN (2005) *The South African Liquor Industry.* Consumer and Corporate Regulation Division (CCRD), Department of Trade and Industry, South Africa.

ARA (2009) *The contribution of the liquor industry to the South African economy.* [Online] Available www.ara.co.za/uploads/DTI-convention-brochure%20final.pdf (Assessed 16 May 2014).

BIER (2014) Beverage industry continues to drive improvement in water and energy Use: Beverage Industry Environmental Roundtable 2013 trends and observations. Europe: Beverage Industry Environmental Roundtable (available from the link: www.bieroundtable.com) (Assessed 20 May 2016).

BRAEKEN L, VAN DER BRUGGEN B and VANDECASTEELE C (2004) Regeneration of brewery wastewater using nanofiltration, Water Research 38 (13) 3075-3082.

COHEN Y. AND ALLEN D (1992) An integrated approach to process waste minimization research. Journal of Hazardous materials 29, 253-273.

DEPARTMENT OF AGRICULTURE, FORESTRY and FISHERIES (DAFF) (2012) Grain Sorghum Market Value Chain Profile [Online] Available: http://www.nda.agric.za/docs/AMCP/Grain2012.pdf. (Accessed 22 February 2015).

DEPARTMENT OF TRADE and INDUSTRY (DTI) (2004) *Study of the liquor industry in South Africa*, March, 1-64 [Online] Available: http://www.dti.gov.za (Accessed: 10 May 2014).

DEWAR J, TAYLOR JR and BERJAK P (1997) Determination of Improved Steeping Conditions for Sorghum Malting. Journal of Cereal Science 26, 129-136.

Diego (2013) Sustainability and Responsibility Report 2013 [Online] Available: www.diageo.com. (Assessed 17 March 2015).

DNA ECONOMICS (2011). *Baseline study of the liquor industry including the impact of the National Liquor Act 59 of 2003*, Department of Trade and Industry Report, Pretoria, South Africa.

ECONEX AND QUANTEC RESEARCH (2010). *Working for South Africa: The contribution of SAB to the South African economy* [Online] Available: http://www.sabmiller.com/docs/default-source/investor-documents/reports/2010/sustainability/working-for-south-africa-2010.pdf?sfvrsn=4 (Assessed 01 April 2015).

ESKOM (2014) *Eskom: Key facts and figures.* Available at: http://www.eskom.co.za/OurCompany/Company Information/Pages/Key_Facts.aspx (Accessed 29 September 2014).

ESKOM MINING EFFICIENCY (2010) *The Energy Efficiency series: Towards an energy efficient mining sector.* Available at: http://www.eskom.co.za/sites/idm/Documents/121040ESKD_Mining_ Brochure_ paths.pdf (Assessed 29 September 2014).

EWS (2011) eThekwini Water and Sanitation: Water Services Development Plan.

EWS (2013) eThekwini Water and Sanitation: Policies and Practices of eThekwini Water and Sanitation Unit.

EWS (2014) eThekwini Water and Sanitation: Tariff Table 2014/2015.

EWS (undated). *eThekwini Water and Sanitation: Sewage disposal bylaws.* Retrieved 2014, from eThekwini Municipality: http://www.durban.gov.za/City_

FILLAUDEAU L, BLANPAIN-AVET P and DAUFIN G (2006) Water, wastewater and waste management in brewing industries, Journal of Cleaner Production 14 463-471.

FOODSTUFFS, COSMETICS AND DISINFECTANTS ACT 54 OF 1972. Available at http://www.gov.za/documents/acts (Assessed 20 May 2015).

GOLDAMMER T (2008) *The Brewers' Handbook, 2nd Edition.* Clifton: Apex Publishers.

KANAGACHANDRAN K and JAYERANTENE R (2006) Utilisation potential of brewery wastewater sludge as an organic fertilizer, Journal of the Institute of Brewing 112 (2) 92-96.

KORONEOS C, ROUMBAS G, GABARI Z, PAPAGIANNIDOU E and MOUSSIOPOULOS N (2005). Life cycle assessment of beer production in Greece. Journal of Cleaner Production 13, 433-439.

LYUMUGABE F, GROS J and NZUNGIZE J (2012) *Characteristics of African traditional beers brewed with sorghum malt: a review.* de l'Université de Liège.

LYUMUGABE J, GROS J, NZUNGIZE E, BAJYANA P and THONART P (2012) Characteristics of African traditional beers brewed with sorghum malt: a review Biotechnology, Agronomy, Society and Environment, 16 (4) 509-530.

LYUMUGABE L, KAMALIZA G, BAJYANA E AND THONART P (2010) Microbiological and physico-chemical characteristics of Rwandese traditional beer "*Ikigage*". African Journal of Biotechnology, 9, 4241-4246.

MATA TM and COSTA CAV (2001) Life cycle assessment of different reuse percentages for glass beer bottles. International Journal of Life Cycle Assessment 6 (5) 307-319.

MUSEE N (2004) *An integrated approach to waste and energy minimization in the wine industry: a knowledge-based decision methodology. PhD dissertation. Department of Process Engineering, University of Stellenbosch, South Africa.* Stellenbosch: Stellenbosch University.

MUSEE N and LORENZEN L (2013) Market dynamics as a driver towards research needs evolution: a case of up-flow anaerobic sludge blanket seeding granules. Water SA 39(1), 131-142.

MUSEE N, LORENZEN L and ALDRICH C (2007). Cellar waste minimization in the wine industry: a systems approach. Journal of Cleaner Production 15 417-431.

NAMC (2007). *Report on the investigation into the Sorghum Industry*, A report by the Section 7 Committee, National Agricultural Marketing Council, Pretoria, South Africa [Online] Available: http://www.namc.co.za/upload/section_7_reports/SORGHUM%20S7%20FINAL%20REPORT%2003.07.mdi.pdf (Assessed: 13 February 2015)

OCCUPATIONAL HEALTH AND SAFETY ACT 85 OF 1993. Available at http://www.gov.za/documents/acts (Assessed 20 May 2015).

OLAJIRE AA (2012) The brewing industry and environmental challenges. Journal of Cleaner Production (in press) (2012) 1-21

PARRY CDH and BENNETTS AL (1998) *Alcohol Policy and Public Health in South Africa.* Cape Town: Oxford University Press.

PELTZER, K and RAMLAGAN S (2009) Alcohol Use Trends in South Africa. Journal of Social Sciences, 18(1): 1-12.

PERRY M, and DE VILLIERS G (2003) Modelling the consumption of water and other utilities, Brauwelt International 5 (3): 286-290.

SABMILLER AND WWF REPORT (2009) *Water footprinting: Identifying & addressing water risks in the value chain*. http://awsassets.panda.org/downloads/sabmiller_water_footprinting_report_final_.pdf (May 20, 2015).

STEFFEN, ROBERTSON and KIRSTEN INC CONSULTING ENGINEERS (1989). *Water and Wastewater Management in the Sorghum Malt And Beer Industries.* Water Research Commission, Pretoria, South Africa.

STEINKRAUS K (2004) *Industrialization of Indigenous Fermented Foods, Revised and Expanded.* CRC Press.

TANGRI N (2003) Waste Incineration: A Dying Technology [online], accessed on 26 October 2015

TAYLOR JR (2004) *Overview: importance of sorghum in Africa.* Pretoria: Department of Food Science, University of Pretoria.

TOKOS H, PINTARIC NZ (2009) Synthesis of batch water network for a brewery plant. Journal of Cleaner Production 2009, 17:1465-1479.

TOKOS H, PINTARIC NZ (2012) Development of a MINLP model for the optimization of a large industrial water system. Optimization and Engineering 13:625-662

TOKOS H, ZORKA NOVAK PINTARIC NZ, YANG Y, KRAVANJA Z (2012) Multilevel strategies for the retrofit of large scale industrial water system: A brewery case stud. AIChE Journal 58(3) 884-898.

UNB ((2013, May 16). *United National Breweries SA – who we are* [Online] Available: http://www.unb.netsource.co.za/view/unb/en/page51.html (Assessed 16 May 2014)

UNB PRESENTATION ON LIQOUR BILL 2003 (2003) United National Sorghum Breweries submission [Online] Available: www.pmg.org.za/docs/2003/appendices/030513ubn.ppt (Accessed May 16, 2014).

US CONGRESS (1990) Pollution Prevention Act of 1990, 42, U.S.C. Sections 13101-6.

APPENDIX A1: BEER PRODUCTION, WATER CONSUMPTION, AND EFFLUENT GENERATION IN BREWING AND MALTING PLANTS

Table A1.1: Beer production and water consumption in months eight months (July 2015 to February 2016).

Brewery	Month	Packaged beer on site (L)	Beer Produced (HL)	Beer production (L)	Water total intake (L)	Specific water intake (L/L)
A	Jul-2015	8 372 820	83 922	8 392 200	26 856 000	3 200
	Aug-2015	8 431 670	84 490	8 449 000	26 957 000	3 191
	Sep-2015	8 160 795	81 650	8 165 000	25 270 000	3 095
	Oct-2015	7 846 035	78 384	7 838 400	26 887 000	3 430
	Nov-2015	7 396 290	73 982	7 398 200	27 433 000	3 708
	Dec-2015	8 285 865	82 928	8 292 800	31 125 000	3 753
	Jan-2016	7 027 815	70 148	7 014 800	30 778 000	4 388
	Feb-2016	7 199 095	71 852	7 185 200	27 302 000	3 800
B	Jul-2015	2 829 070	28 781	2 878 082	10 016 000	3 480
	Aug-2015	2 978 945	29 909	2 990 896	10 517 000	3 516
	Sep-2015	3 014 109	30 468	3 046 777	9 719 000	3 190
	Oct-2015	3 195 642	32 319	3 231 940	10 401 000	3 218
	Nov-2015	3 014 290	31 560	3 156 000	9 890 000	3 134
	Dec-2015	2 954 683	30 875	3 087 500	9 161 000	2 967
	Jan-2016	2 821 646	28 802	2 880 241	9 319 000	3 235
	Feb-2016	2 905 411	29 870	2 986 991	8 389 000	2 809
C	Jul-2015	4 595 575	47 850	4 785 000	15 790 000	3 300
	Aug-2015	4 658 620	47 970	4 797 000	16 555 000	3 451
	Sep-2015	4 717 060	48 560	4 856 000	17 035 000	3 508
	Oct-2015	4 177 720	43 260	4 326 000	18 397 000	4 253
	Nov-2015	3 832 300	39 560	3 956 000	15 364 000	3 884
	Dec-2015	4 289 685	43 920	4 392 000	14 111 000	3 213
	Jan-2015	3 000 415	31 790	3 179 000	17 564 000	5 525
	Feb-2015	3 593 964	38 191	3 819 100	15 517 000	4 063
D	Jul-2015	2 683 312	26 520	2 652 000	9 567 000	3 607
	Aug-2015	2 754 184	27 781	2 778 100	9 167 000	3 300
	Sep-2015	2 947 404	29 701	2 970 100	9 571 000	3 222
	Oct-2015	2 903 716	29 279	2 927 900	9 497 000	3 244
	Nov-2015	3 017 988	30 444	3 044 400	10 083 000	3 312
	Dec-2015	2 508 524	25 405	2 540 500	9 931 000	3 909
	Jan-2015	2 368 972	24 421	2 442 100	10 000 000	4 095
	Feb-2015	2 411 934	24 159	2 415 900	8 185 000	3 388

Table A1.2. Effluent generation in eight months (July 2015 to February 2016), and the estimation of specific volume (SEV).

Brewery	Month	Beer production (L)	Water total intake (L)	Effluent generated (L)	Effluent % (of intake water)	SEV
A	Jul-2015	8 392 200	26 856 000	15 711 024	58.50	1.87
	Aug-2015	8 449 000	26 957 000	15 747 900	58.42	1.86
	Sep-2015	8 165 000	25 270 000	14 547 000	57.57	1.78
	Oct-2015	7 838 400	26 887 000	16 225 028	60.35	2.07
	Nov-2015	7 398 200	27 433 000	17 081 964	62.27	2.31
	Dec-2015	8 292 800	31 125 000	19 469 836	62.55	2.35
	Jan-2016	7 014 800	30 778 000	20 296 056	65.94	2.89
	Feb-2016	7 185 200	27 302 000	17 156 744	62.84	2.39
	Average	**7 841 950**	**27 826 000**	**17 029 444**	**61.05**	**2.19**
B	Jul-2015	2 878 082	10 016 000	4 937 000	49.29	3.48
	Aug-2015	2 990 896	10 517 000	4 844 000	46.06	3.52
	Sep-2015	3 046 777	9 719 000	4 759 000	48.97	3.19
	Oct-2015	3 231 940	10 401 000	6 421 000	61.73	3.22
	Nov-2015	3 156 000	9 890 000	4 896 000	49.50	3.13
	Dec-2015	3 087 500	9 161 000	4 146 000	45.26	2.97
	Jan-2016	2 880 241	9 319 000	2 902 000	31.14	3.24
	Feb-2016	2 986 991	8 389 000	4 409 000	52.56	2.81
	Average	**3 032 303**	**9 676 500**	**4 664 250**	**48.06**	**3.19**
C	Jul-2015	4 785 000	15 790 000	11 568 742	73.27	2.42
	Aug-2015	4 797 000	16 555 000	12 299 973	74.30	2.56
	Sep-2015	4 856 000	17 035 000	12 727 123	74.71	2.62
	Oct-2015	4 326 000	18 397 000	14 089 123	76.58	3.26
	Nov-2015	3 956 000	15 364 000	11 859 265	77.19	3.00
	Dec-2015	4 392 000	14 111 000	10 204 242	72.31	2.32
	Jan-2015	3 179 000	17 564 000	14 783 264	84.17	4.65
	Feb-2015	3 819 100	15 517 000	12 181 122	78.50	3.19
	Average	**4 263 763**	**16 291 625**	**12 464 107**	**76.38**	**3.00**
D	Jul-2015	2 652 000	9 567 000	6 276 540	65.61	2.37
	Aug-2015	2 778 100	9 167 000	5 805 572	63.33	2.09
	Sep-2015	2 970 100	9 571 000	6 000 212	62.69	2.02
	Oct-2015	2 927 900	9 497 000	5 970 748	62.87	2.04
	Nov-2015	3 044 400	10 083 000	6 395 628	63.43	2.10
	Dec-2015	2 540 500	9 931 000	6 702 260	67.49	2.64
	Jan-2015	2 442 100	10 000 000	6 850 952	68.51	2.81
	Feb-2015	2 415 900	8 185 000	5 240 508	64.03	2.17
	Average	**2 721 375**	**9 500 125**	**6 155 303**	**64.74**	**2.28**

Table A1.3. Waste generation from brewing plants for eight months (July 2015 to February 2016), and each type per 1000 L of beer produced.

Brewery	Month	Beer produced (litres)	Spent grain (Tons)	Maroek (effluent straining) (Tons)	Coal Ash from boilers (Tons)	Spent grain per1000 L of beer (kg/L)	Maroek per 1000L of beer (kg/L)	Coal ash per 1000 L of beer (kg/L)
A	Jul-2015	8 392 200	609.02	78.78	74.74	72.57	9.39	8.91
	Aug-2015	8 449 000	613.14	78.85	74.81	72.57	9.33	8.85
	Sep-2015	8 165 000	592.53	77.03	72.79	72.57	9.43	8.92
	Oct-2015	7 838 400	568.83	76.41	72.11	72.57	9.75	9.20
	Nov-2015	7 398 200	536.89	65.27	59.76	72.57	8.82	8.08
	Dec-2015	8 292 800	601.81	71.48	66.64	72.57	8.62	8.04
	Jan-2016	7 014 800	509.06	67.57	62.31	72.57	9.63	8.88
	Feb-2016	7 185 200	521.43	68.01	62.79	72.57	9.47	8.74
	Average	**7 841 950**	**569.09**	**72.93**	**68.24**	**72.57**	**9.31**	**8.70**
B	Jul-2015	2 878 082	196.11	55.26	52.558	68.14	38.40	18.26
	Aug-2015	2 990 896	225.27	41.24	45.773	75.32	27.58	15.30
	Sep-2015	3 046 777	195.19	44.52	47.249	64.06	29.22	15.51
	Oct-2015	3 231 940	220.52	47.58	53.096	68.23	29.44	16.43
	Nov-2015	3 156 000	208.33	42.72	35.006	66.01	27.07	11.09
	Dec-2015	3 087 500	240.74	43.32	46.203	77.97	28.06	14.96
	Jan-2016	2 880 241	177.04	38.18	37.323	61.47	26.51	12.96
	Feb-2016	2 986 991	217.30	31.28	46.093	72.75	20.95	15.43
	Average	**3 032 303**	**210.06**	**43.01**	**45.41**	**69.24**	**28.40**	**14.99**
C	Jul-2015	4 785 000	429.90	66.10	52.832	89.84	13.81	11.04
	Aug-2015	4 797 000	391.70	28.30	55.880	81.66	5.90	11.65
	Sep-2015	4 856 000	412.70	59.70	53.340	84.99	12.29	10.98
	Oct-2015	4 326 000	389.30	60.56	48.260	89.99	14.00	11.16
	Nov-2015	3 956 000	339.90	57.00	43.104	85.92	14.41	10.90
	Dec-2015	4 392 000	459.30	48.40	50.419	104.58	11.02	11.48
	Jan-2016	3 179 000	290.40	75.40	36.322	91.35	23.72	11.43
	Feb-2016	3 819 100	368.20	53.47	41.478	96.41	14.00	10.86
	Average	**4 263 763**	**385.18**	**56.12**	**47.70**	**90.59**	**13.64**	**11.19**
D	Jul-2015	2 652 000	183.77	31.82	30.988	69.29	12.00	11.68
	Aug-2015	2 778 100	187.66	33.34	30.988	67.55	12.00	11.15
	Sep-2015	2 970 100	168.37	35.64	32.258	56.69	12.00	10.86
	Oct-2015	2 927 900	145.09	35.13	35.560	49.55	12.00	12.15
	Nov-2015	3 044 400	125.47	36.53	30.734	41.21	12.00	10.10
	Dec-2015	2 540 500	111.42	30.49	28.956	43.86	12.00	11.40
	Jan-2016	2 442 100	103.58	29.31	29.464	42.42	12.00	12.07
	Feb-2016	2 415 900	106.48	28.99	30.480	44.07	12.00	12.62
	Average	**2 721 375**	**141.48**	**32.66**	**31.18**	**51.83**	**12.00**	**11.50**

APPENDIX A2: MAINS WATER AND EFFLUENT QUALITY IN MALT BREWERIES

Table A2.1: Municipal main water quality over 3 months used in sorghum beer brewing plants

Plants	A					B					C					D				
Parameters	pH	TH	Ca^{2+}	TDS	Ch	pH	TH	Ca^{2+}	TDS	Ch	pH	TH	Ca^{2+}	TDS	Ch	pH	TH	Ca^{2+}	TDS	Ch
Result limits	6-9	6-240	6-240	10-350	5-50	6-9	6-240	6-240	10-350	5-50	6-9	6-240	6-240	10-350	5-50	6-9	6-240	6-240	10-350	5-50
Jun-14 (Avg.)	7.36	154	82	149	24	8.09	32	NR	155	7	7.34	NR	75	85	79	8.09	256	255	445	31
Jul-14 (Avg.)	7.29	139	92	144	14	7.72	32	NR	143	27	7.98	NR	74	326	73	8.21	244	166	453	37
Aug-14 (Avg.)	7.85	115	95	148	18	7.31	38	NR	135	29	8.12	NR	74	333	87	7.96	270	262	483	37
Max value	7.97	236	140	160	36	8.71	143	NR	197	52	9.95	NR	120	680	468	8.72	420	320	720	46
Min Value	6.67	88	16	140	8	6.91	10	NR	126	0	6.10	NR	0	10	8	7.39	79	40	320	25

Abbreviations: Avg.: average, TH: total hardness (mg/L), Ca^{2+} hardness due to calcium ions (mg/L), TDS: total dissolved solids (mg/L), Ch: chlorides (mg/L); NR: Not reported

Table A2.2: Effluent characteristics over 3 months generated from sorghum beer brewing plants.

Plants	A					B					C					D				
Parameters	pH	SS	COD	TS (%)	TDS	pH	SS	COD	TS (%)	TDS	pH	SS	COD	TS (%)	TDS	pH	SS	COD	TS (%)	TDS
Result limits	6-9	1-100	50-2500	0.2-2	200-2000	6-9	1-100	50-2500	0.2-2	200-2000	6-9	1-100	50-2500	0.2-2	200-2000	6-9	1-100	50-2500	0.2-2	200-2000
Jun-14 (Avg.)	3.65	8.35	2075	1.89	728	6.71	20.00	NR	0.23	NR	7.34	NR	75	85	79	NR	NR	NR	NR	NR
Jul-14 (Avg.)	4.44	4.83	1775	1.68	1515	6.63	89.71	NR	0.17	50	7.98	NR	74	326	73	7.11	244	166	453	600
Aug-14(Avg.)	3.50	32.75	2215	1.90	1475	6.62	53.63	NR	0.75	NR	8.12	NR	74	333	87	NR	NR	NR	NR	NR
Max value	5.33	60.00	2530	1.50	1550	10.30	180	NR	1.39	NR	9.95	NR	120	680	468	-	-	-	-	-
Min Value	3.20	4.50	1654	1.96	200	4.36	6	NR	0.00	NR	6.10	NR	0	10	8	-	-	-	-	-
Avg. values	3.86	15	2022	1.82	1239	6.65	54.45	-	0.38	-	7.81	-	74.33	248.00	79.67	-	-	-	-	-

Abbreviations: Avg.: average, COD: carbon oxygen demand (mg/L), SS: suspended solids (mg/L), TDS: total dissolved solids (mg/L), TS: chlorides (mg/L); NR: Not reported, (-): interminable due to lack of data. *O-Absorption and conductivity parameters although were set at limits of 20-250 and 300-2500, respectively, but no records were kept for all the breweries. SS: settling solids, COD: carbon oxygen demand, TDS: total dissolved solids.

9781431208579