Influence of Residence Time and Fine Grinding on PGMS Recovery and Grade Using a Float Characteristic Test Rig

Edison Muzenda, John Kabuba, Freeman Ntuli and Mansoor Mollagee

***Abstract*—**This paper is a revised version of our previous paper entitled "The investigation of residence time and fine grinding using a float characteristic test rig" presented at Communition 2010, Cape Town. The objective of this work was to investigate the possibility of improving the Platinum Group Metal (PGM) recovery by reducing the secondary cleaner tails grade to below 2g/t. This was achieved by increasing the flotation residence time with a Float Characteristic Test Rig (FCTR) and grinding secondary cleaner tails using ultra-fine technology and floating in the FCTR. PGM and grind fine analysis were performed on the collected samples and showed a 9.9% grind improvement when the secondary clear tails (SCT) were milled. A PGM mass balance analysis was performed to determine the mass flow rate, mass pull and total recovery which indicated the SCT reduction after milling and floatation. The Deswik milling increased the cumulative recovery and mass pulls from 57 to 82% and 16.5 to 57.6% respectively.

***Keywords*—**Float Characteristic Test Rig (FCTR), Grinding, Platinum Group Metal (PGM), Residence time, Secondary Cleaner tails (SCT).

I. Introduction

THE ore is crushed and milled to reduce the size of the rock particle and expose the minerals which contain PGMs [1], [2]. Ores from the Merensky reef and UG2 reef are generally sulphide- poor with platinum and other PGE present in a large variety of discrete PGMs [3]. The initial phase of processing both reef type ores is identical. Ore is fed into a primary crusher from where it undergoes one or more stages of secondary crushing. At each stage vibrating screens allow material of the appropriate size to pass on to the rest of the processing circuit. Crushing followed by fine grinding, also known as milling, is used to maximise separation of the ore minerals from the gangue [4]. Typically, Merensky ores are milled to about 60% passing of 75 µm and have bond work indices of about 21kWh/t at the coarser sizes and up to 25kWh/t at the finer 200 mesh size. Some mines have introduced one or more additional stages after crushing and milling to optimise PGE recovery [5]. Ultrafine technology is gaining significant acceptance as a cost effective means to provide an optimum grade/recovery response in flotation [5]. Long residence times are typical of the flotation plants because of the high value of the recovered material. A residence time greater than 60 minutes in the main stream of flotation is not uncommon [7]. The main purpose of this work was to investigate the possibility of PGM recovery by reducing the secondary cleaner tails grade to below 2g/t. A Deswik mill was used to grind feed material to a specific particle size and distribution, ensuring improved performance of downstream metallurgical flotation processes. This revolutionary new mill has proved to be highly efficient for the reduction of metal bearing ores resulting in greater liberation of primary material resulting in higher froth flotation recovery rates.

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II. Sample Collection and Preparation

The samples were collected for residence time and fine grind analysis. Blank test work was used with a dosing of 300 g/t of depressant (without DM), Fig. 1. Fine grind test work dosing 300 g/t depressant (with DM), Fig.3. The samples were weighted wet and dry to determine the % solid. They were then oven dried and pulverised. The grinding analysis was performed on Deswik feed (before milling) and Deswik product (after milling). All the samples collected were prepared and subjected to fire assay analysis to determine the PGM content.

III. Methodology

The FCTR consisted of 3x150L rougher and 1x50L cleaner cells, Fig. 1. The pipe construction was done from the main plant secondary cleaner sump pump to the Magna thickener and the return pipe was also constructed from the Magna thickener underflow to the Pilot Plant approximately 120 m away. Fine grinding test work was conducted on the secondary cleaner tails. These tails are of lower grade (i.e. < 2 g/t) since there is no tailing treatment plant. The secondary cleaner tails increased from 2.77 g/t to approximately 3.87 g/t. It was then decided to investigate the fine grinding technology to reduce the tails grade to below 2 g/t. This would then result in the final tails grade being reduced and hence improved recovery. The fine grinding would be obtained using the Deswick Mill, the procedure of processing the secondary cleaner is explained commencing from the pipe connections. The PVC pipe line (90 mm) was constructed from the secondary cleaner tails sump pump to the centre of the thickener. The thickener overflow was pumped to the tailings thickener. The Deswik mill was used to grind feed material to a specific particle size and distribution.

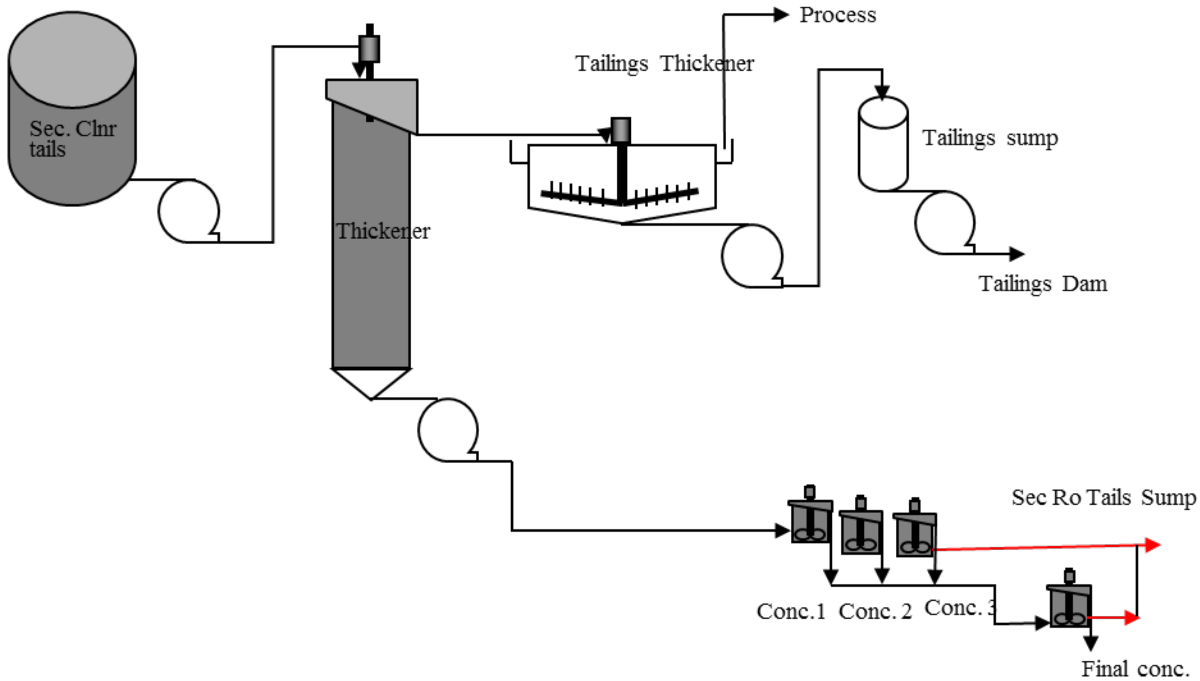

Fig.1 Residence time test work diagram, FCTR without Deswik Mill

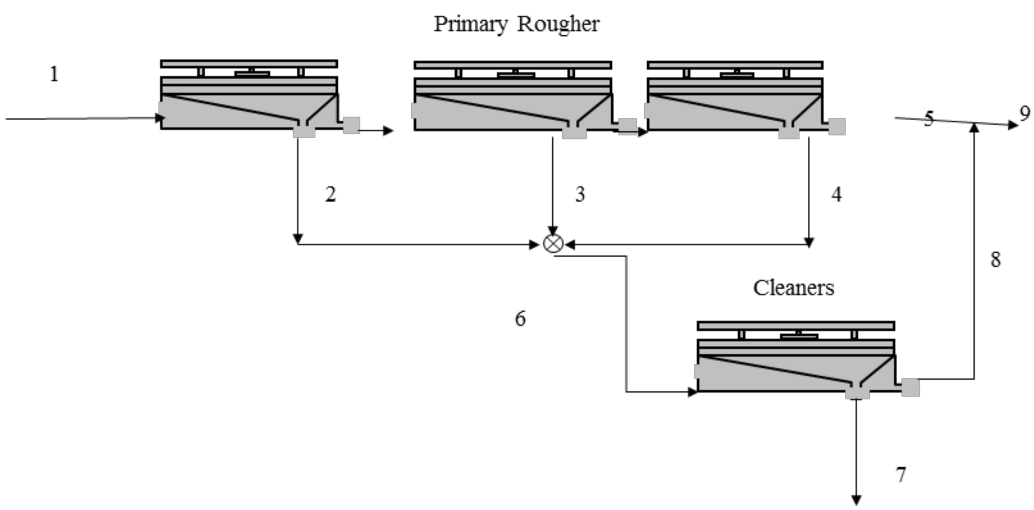

Fig. 2 Mass balance diagram, FCTR without Deswik Mill

TABLE 1
STREAM FLOW RATE, FCTR WITHOUT DESWIK MILL

Stream	1	2	3	4	5	6	7	8	9
Stream type	New feed	Conc 1	Conc 2	Conc 3	R tails	Comb conc	Clnr conc	Clnr tails	Final tails
Solids	100	2.04	1.335	1.571	95.049	4.951	0.303	4.648	99.697
Water	336.7	44.789	27.788	28.1	236.004	100.677	8.453	92.224	328.228
PGMs	234	26.005	18.512	12.608	176.875	57.125	12.347	44.778	221.653

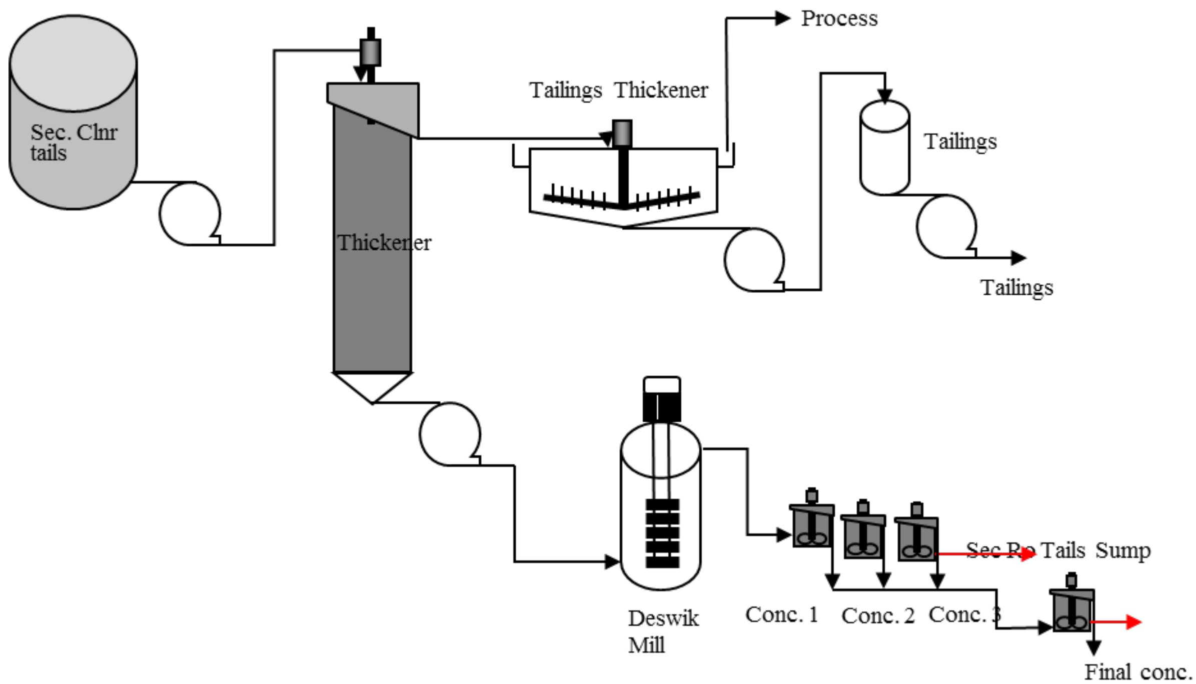

Fig. 3 Fine grinding test work diagram, FCTR with Deswik Mill

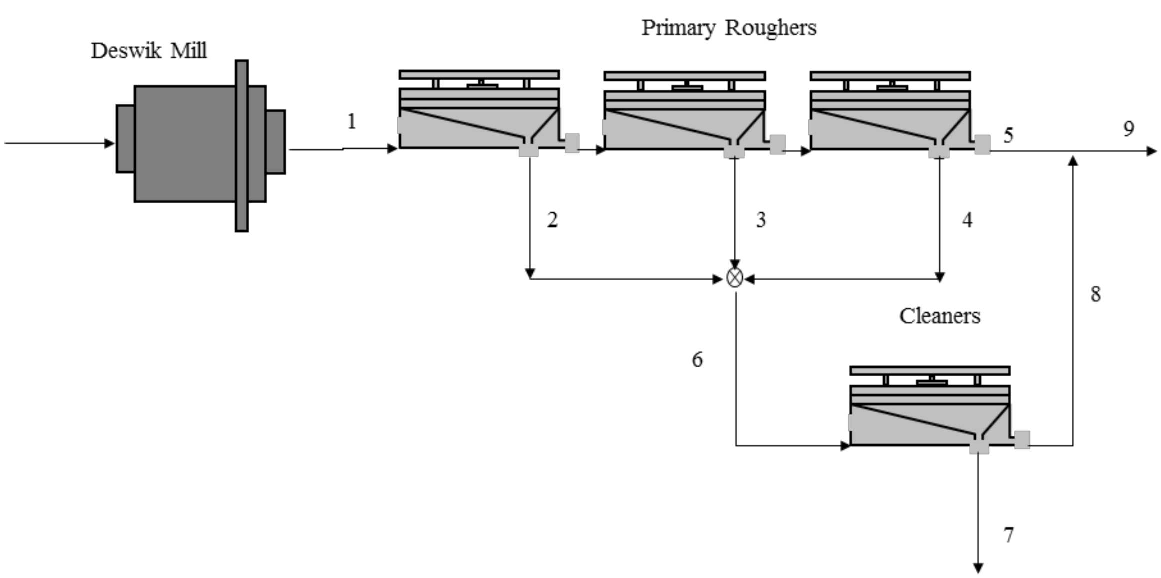

Fig. 4 Mass balance diagram, FCTR with Deswik Mill

TABLE II
STREAM FLOW RATE, FCTR WITH DESWIK MILL

Stream	1	2	3	4	5	6	7	8	9
Stream type	New feed	Conc 1	Conc 2	Conc 3	R tails	Comb conc	Clnr conc	Clnr tails	Final tails
Solids	100	10.152	2.256	4.326	83.266	16.734	3.058	13.676	96.942
Water	417.866	81.106	17.285	49.678	269.797	148.069	8.847	139.222	409.019
PGMs	325	124.7	23.658	29.427	147.215	177.785	91.871	85.914	221.653

IV. EXPERIMENTAL SETUP

A. Milling Circuit

The most prevalent circuit configuration used in Platinum industry is the Mill Float (MF2) circuit. Fig 5. The run of mine ore is stored in silo and fed to the Primary mill via vibrators. Primary mill operating at the feed rate of 180t/h produces a product of between 45-50% passing 75µm using 80 mm high chrome steel balls. The milled product passed different stages of classifiers to screen out woodchips and larger particles and circulated back to the mill for regrind.

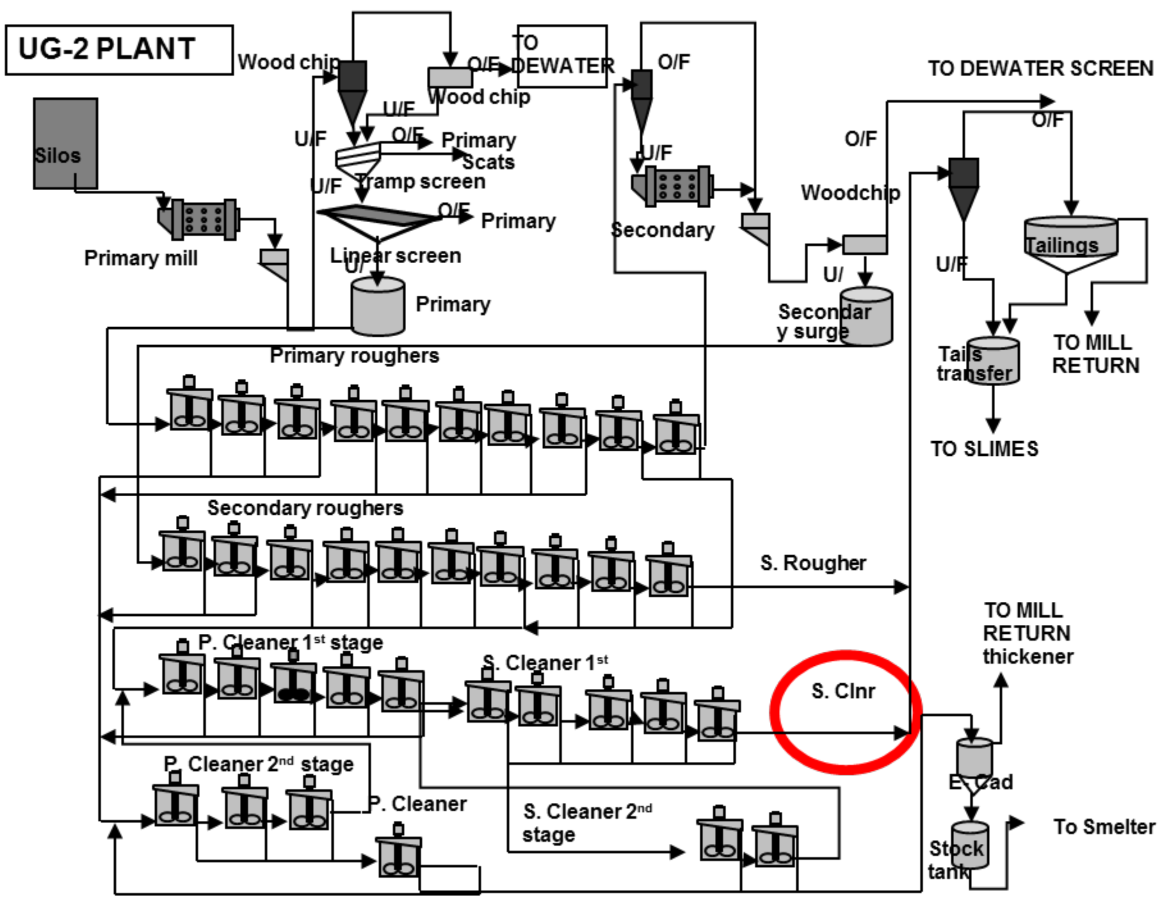

Fig. 5 Simplified UG-2 plant flow sheet

The aperture size used for screening out larger material was 1.5mm. Then product from the classifier (underflow) in slurry form was fed to primary flotation unit. Concentrate was further upgraded and the tails processed to secondary milling. In secondary milling (regrinding) the degree of liberation is increased. The secondary mill was of the same size as the primary mill and also drew the same power. The advantage of primary milling is that the feed is already in a slurry form and will not require inlet water except for density adjustment purposes. It was intruded because the primary mill cannot produce the required size reduction to liberate all valuable mineral particles. The feed to the secondary mill passes through the cyclone densifier before being fed to the mill and the water that was removed was added back at the discharge sump for density adjustment. The secondary mill product ranged between 75-80% passing 75μm using 40mm high chrome steel balls. Then the milled product was fed to secondary flotation to recover slow floating minerals, which is the material that was not recovered from the primary stage and locked in time rocks.

B. Flotation Circuit

- Primary rougher: this is the first stage where all readily floatable material is recovered. This stage does not produce an acceptable concentrate grade thus a cleaner circuit will be used. The process consisted of 10x20m3 primary float cells in series and secondary rougher consisted of 10x20m3 float cells in series.
- Cleaner floatation: this is usually applied to rougher concentrate; here the materials are floated more gently with deep froth depth to allow cleaning of the floating particle. The cleaner stages consisted of primary and secondary cleaner stages.
- Scavenger floatation: this is usually performed with the tails to float in the initial rougher stage and then the scavenger after further milling. The concentrate from the scavenger is further upgraded in a secondary cleaner stage. Both concentrate from the primary re-cleaner ranging from 400-500g/t and secondary cleaner concentrate from 20-30g/t were collected and dispatched to the smelter as combined concentrate ranging from 340-380 g/t for further upgrading via tankers. The final tails from the plant was a combination of secondary rougher and secondary cleaner. Fig. 5.

V. RESULTS & DISCUSSION

The milled samples were analysed using the Malvern Analyser to determine the grind analysis. The sample from the grind analysis had a 9.9% grind improvement when the SCT was milled. The mass balance from the PGM analysis was performed using a solver programme to determine the mass flow rate, mass pull and total recovery which indicated the SCT reduction after milling and floating. The results are shown in Table 3.

TABLE III
INFLUENCE OF DESWIK MILL ON MASS PULL AND RECOVERY

	% Mass Pull	Recovery
Without Deswik Mill	16.5	5.12
With Deswik Mill	57.57	28.64

A. Deswik Mill

The grinding analysis was performed on Deswik mill feed and Deswick mill product using the Malvern analyser. The Deswik power drawn per ton during the test work was between 4-10 kWh/t. The mill was filled with the media to 80% capacity for the optimal operation. The mill product was then floated at the FCTR.

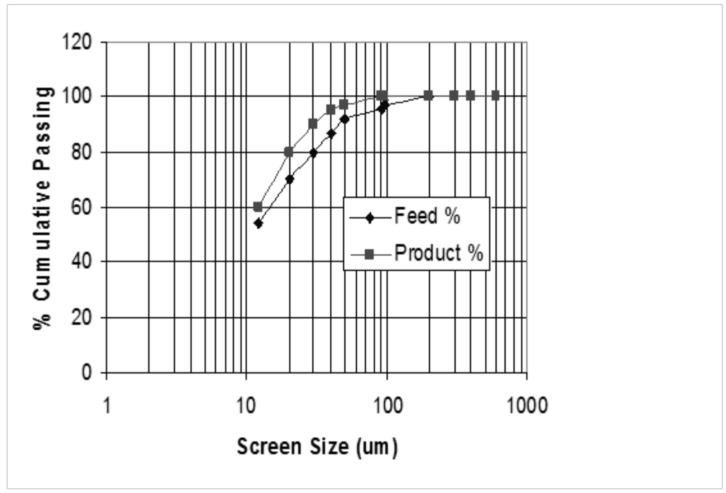

Fig. 6 % cumulative passing after Deswik grinding

From Fig. 6, the feed to the DM mill grind at □m was found to be of 54.28% passing at □m and the Deswik product was 60.25% passing at □m. These indicated approximately 9.9% improvement on grade. Fig. 7 shows the improvement in PGM grade and recovery after ultrafine technology grinding.

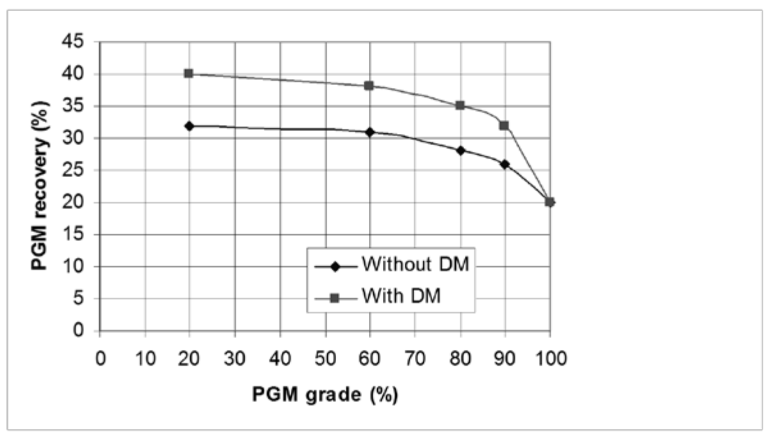

Fig. 7 Improvement in the PGM grade/ recovery using ultrafine technology

The relationship between mill resistance time and particle size for both mills is shown in Fig. 8. The residence time for the two mills were similar for product sizes down to 80% passing 25 microns and below this point the residence time required by the DM to achieve a specified grind was reduced from 16.24 to 11.38 minutes.

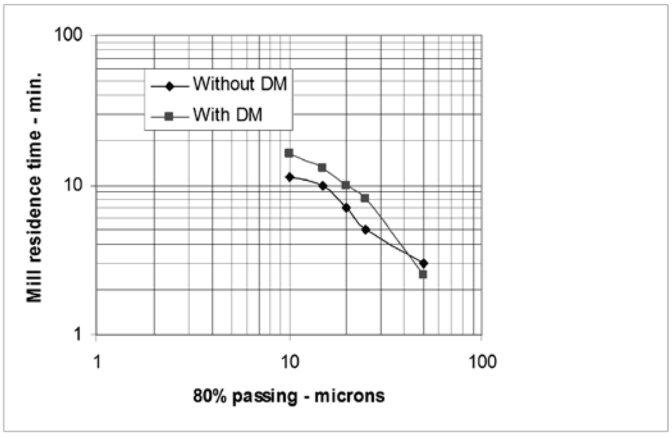

Fig. 8 Variation of residence with milling type

B. Float Characteristic Test Rig

- **Milling circuit:** The main plant feed grade analysis on primary and secondary mills were 45% and 78% passing at 75µm. The primary mill (80 mm steel ball) operated at 75% critical speed and drew a power of 2250 kW and secondary mill drew a power of 2100 kW filled with 40 mm steel balls and operating at 75% critical speed.
- **Floatation circuit:** The following reagent conditions were used: frother at 25 g/t, rougher depressant at 80 g/t, cleaner depressant at 40 g/t, copper sulphate at 100 g/t, xanthate at 130 g/t. The measured float density on the primary and secondary rougher was 1.35 and 1.37 kg/m3 respectively. The main plant secondary cleaner tails results obtained ranged from 3.37 to 3.93 g/t.
- **Thickening:** The required density to conduct the test work was between 1.20 kg/m3 - 1.25 kg/m3. From the test work the densities from residence and fine grinding were 1.178 kg/m3 and 1.162 kg/m3 respectively. The test work was conducted under conditions and the pump output was at 50% to prevent dilution.
- **Samples:** The samples collected are shown in Tables 4 & 6. As indicated for both tests 300 g/t of depressant was added to improve the quality of the froth. The % solids of the cleaner concentrate from the first test, Table 4 without DM and second test Table 6, test with DM were 3.62% and 25.48% respectively. On the second test, the feed was more liberated compared to the firs. The concentrate from the second test was also denser than that from the first.

The mass balances without Deswik Mill, Table 5 indicated a cumulative recovery and mass pull of 51 and 16.5 % respectively. It was also possible to reduce the cleaner tails by 5.13%.

TABLE IV
TEST RESULTS WITHOUT DESWIK MILL

Sample	Net wet (g)	Net dry (g)	Solids (%)	PGM (g/t)	Cr_2CO_3 (%)
Feed A	48679.7	11147	22.9	2.34	8.66
Rougher conc 1	11938.4	507	4.25	13.3	10.5
Rougher conc 2	9891.5	437	4.42	13.6	10.8
Rougher conc 3	10102.8	577	5.71	8	10.9
Rougher tails A	23391.2	6427	27.48	1.91	9
Cleaner feed A	21914.9	1007	4.6	10.7	10.8
Cleaner Conc 1	10851.5	397	3.62	39.6	9.25
Cleaner Tail	23161.9	1167	5.04	10.4	10.9
Final Tail	43469.5	10107	23.25	2.17	8.05

TABLE V
MASS BALANCES WITHOUT DESWIK MILL

	Conc1	Conc 2	Conc 3	Comb conc	Clnr conc	Final Tail
Conc	13.3	13.6	8	10.7	39.6	
Tail	2.12	1.96	1.86		9.63	2.17
Conc. Mass	2.04	1.34	1.53	4.95	0.3	
Tail mass	97.96	96.63	95.05		4.65	4.65
Unit recovery	11.62	8.73	6.66		22.65	
Unit recovery (5)	29.24	21.98	16.76		57.01	
Cumulative recovery	11.62	19.38	24.77		29.9	
Mass pull	2.04	1.36	1.63		6.12	
Cum mass pull	2.04	3.38	4.96		16.5	
Total recovery	**5.13**					

The mass balances with Deswik Mill, Table 7 indicated cumulative recovery and mass pull of 82 and 57.6 % respectively and the cleaner tails were reduced by 28.6%. This was a result of increased liberation.

TABLE VI
TEST RESULTS DESWIK MILL

Sample	Net wet (g)	Net dry (g)	Solids (%)	PGM (g/t)	Cr_2CO_3 (%)
Feed A	14755	2849.4	19.31	3.25	8.66
Rougher conc 1	4003.8	459.1	11.47	11.9	10.5
Rougher conc 2	3479	396.6	11.4	10.4	10.8
Rougher conc 3	3843.3	313.2	8.15	6.75	10.9
Rougher tails A	7452.4	1723	23.12	1.78	9
Cleaner feed A	7516.6	760.5	10.12	10.8	10.8
Cleaner Conc 1	3786.8	964.9	25.48	30.4	9.25
Cleaner Tail	7301.1	619.8	8.49	6.4	10.9
Final Tail	5827.2	2798.4	17.68	2.35	8.05

TABLE VII
MASS BALANCES WITH DESWIK MILL

	Conc1	Conc 2	Conc 3	Comb conc	Clnr conc	Final Tail
Conc	11.9	10.4	6.75	10.8	33.4	
Tail	2.22	2.02	1.77		6.4	2.35
Conc. Mass	10.15	2.26	4.33	16.73	3.06	
Tail mass	89.85	87.59	83.27		13.68	96.94
Unit recovery	37.17	11.76	16.5		51.45	
Unit recovery (5)	129.95	41.12	57.7		179.87	
Cumulative recovery	37.17	44.39	53.38		81.98	
Mass pull	10.15	2.51	4.94		18.28	
Cum mass pull	10.15	12.41	16.73		57.57	
Total recovery	**28.6**					

Use either SI (MKS) or CGS as primary units. (SI units are strongly encouraged.) English units may be used as secondary units (in parentheses). **This applies to papers in data storage.** For example, write "15 Gb/cm^2 (100 Gb/in^2)." An exception is when English units are used as identifiers in trade, such as "3½ in disk drive." Avoid combining SI and CGS units, such as current in amperes and magnetic field in oersteds. This often leads to confusion because equations do not balance dimensionally. If you must use mixed units, clearly state the units for each quantity in an equation.

The SI unit for magnetic field strength H is A/m. However, if you wish to use units of T, either refers to magnetic flux density B or magnetic field strength symbolized as $\mu_0 H$. Use the center dot to separate compound units, e.g., "A·m^2."

VI. Conclusion

The flotation process was not efficient without adding the depressant at the FCTR. With low density there was a 9.9% improvement on grind from the Deswik mill. The % solids increased from 3.62 to 25.48% on cleaner concentrate 1. Using fine grinding instead of increased residence time, the cumulative mass pull and recovery increased from 16.5 to 57.6% and 51 to 82% respectively. Fine grinding also reduced cleaner tails by 28.6% while increased residence time gave a reduction of 5.1%.

Acknowledgment

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Effect of Planting Dates on Yield and Yield Components of Dual Purpose Wheat

Fazal Munsif and Muhammad Arif

Abstract— Dual-purpose (DP) wheat is important for increasing income stability without upsetting the existing cropping system. The experiments were laid out in randomized complete block design with split plot arrangement having three replications during winter 2009-10 and 2010-11. Six wheat cultivars, three planting dates (15th October, 30th October and 14th November) and two cutting treatments (cut and no-cut) were used. Finding showed that higher fodder yield, spikes, heavier grains, greater grain and biological yields were recorded during 2^{nd} year as compared to 1^{st} year. Early planting in mid and end of October resulted in higher fodder yield, grain and biological yields and heavier grains spike^{-1}. Wheat cultivar Siran-2008, Uqab-2000 and Saleem-2000 produced higher fodder biological and grains yields. Cutting reduced grain weight, biological and grain yields. It was concluded that dual purpose wheat system had higher profitability (11.20%) though it produced 3% less grain yield as compared to wheat system aimed for grain only purpose.

Keywords—Cultivars, dual purpose wheat, planting dates.

I. Introduction

WHEAT (*Triticum aestivum* L.) being world first ranked grain crop is the mainstay of the agricultural economy of Pakistan and occupies key role in agricultural policies of the country (1). Wheat is generally cultivated for only grain production, but in countries like Argentina, Australia, Morocco, Syria and Uruguay, it is commonly grown both as fodder and grain purposes crop for livestock due to its palatability, higher crude protein and digestibility compared to fodder crops (5). About 2.45 million hectares area is under fodder crops cultivation, which seldom meet the requirement of fodder for huge number of livestock. Furthermore, low yield per unit area is also one of the constraints in the availability of fodder supply. Thus in order to reduce area competition between fodder and grain crops without upsetting of the present cropping system, there is imperative need for the development of a technology of dual purpose cropping system such as wheat.

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Dual-purpose wheat means getting fodder by giving a cut before 1st node formation (jointing or stem elongation stage) as well as grain at maturity from the same crop of wheat. Among various factors responsible for management of dual purpose wheat system in the country, planting time and selection of best cultivars are of utmost importance (3).

Wheat has its own definite requirements for temperature and light for emergence, growth and flowering. For optimal planting date, cutting will not be expected to adversely affect grain yield of dual-purpose wheat. Selection of high yielding fodder and grain wheat cultivars could be an innovative approach to follow improved marketability of wheat due to both commodities which will enhance income generation from DP wheat cultivation. Choice of cultivar heavily depend on higher fodder production, which might be the genetic difference among wheat cultivars, but the genetic capacity for fodder production is not related to grain yield capacity (8). Introduction of wheat cultivars with good forage and grain production in such areas could provide alternative ways to meet daily requirement of livestock without affecting grain production.

Keeping in view the ever increasing demand of both grain and fodder production in the country, the present experiments were conducted with the aims to determine the optimal planting date and wheat cultivars suitable for dual purpose system and to compare the economic returns of dual purpose and grain only wheat.

II. Material and Methods

The experiments were carried out at New Developmental Farm of Khyber Pakhtunkhwa Agricultural University Peshawar during winter 2009-10 and 2010-2011. The treatments were consisted of three planting dates (D), six cultivars (Cv) and two cutting treatments (C). Three planting dates (15^{th} October, 30^{th} October and 14^{th} November), six cultivars {Saleem -2000, Bathoor-2007 (Bath), Fakhre sarhad-99 (FS-99), Uqab-2000, Siran-2008, and Ghaznavi-98)} and two cutting treatments (Cut and no-cut) were included in the experiment. Wheat cultivars were selected on the basis of higher tillering capacity, intermediate maturity and semi dwarf stature and higher grain yield compared to the other existence cultivars in the region and were sown at three planting dates, starting from early to optimum and was given a cut 70 days after sowing. The experiment was laid out in randomized complete block design with split plot arrangement having three replications. Treatment combinations of planting dates and cutting were kept in the main plots, while wheat cultivars were allotted to sub plots. A plot size of 4 m by 3 m with row-