The Laboratories of the Chair of Mineral Processing

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INTRODUCTION

Since April 2011 the laboratories of the Chair of Mineral Processing have been situated on the first and second floor of the so-called

Impulszentrum Rohstoffe (IZ-Rohstoffe)
Montanuniversitaet Leoben
Rosseggerstrasse 11a
A-8700 Leoben

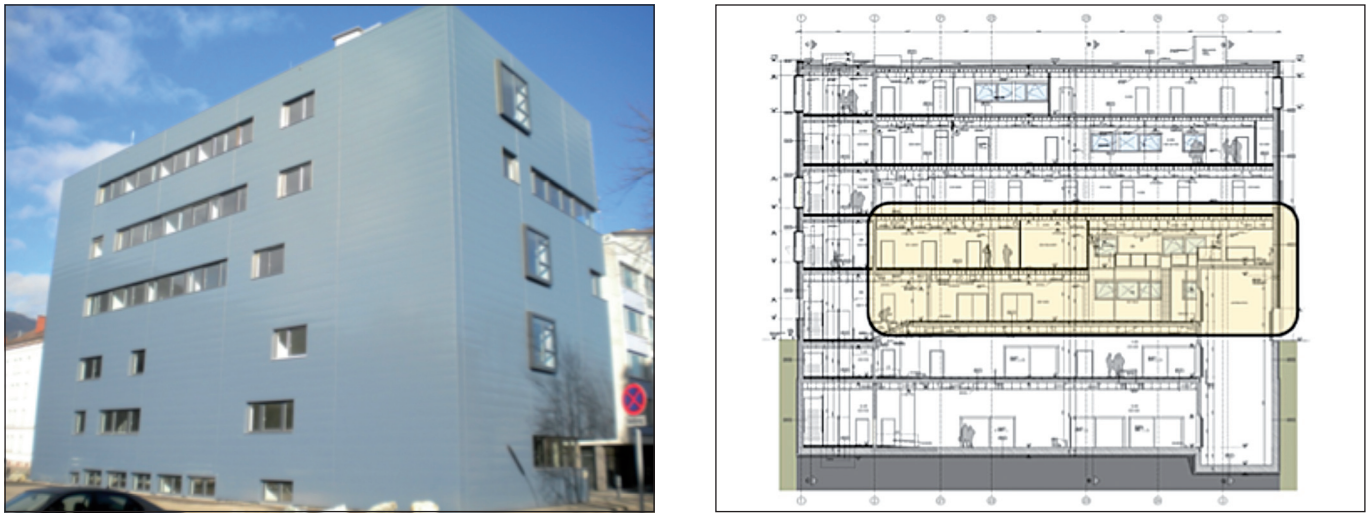

Figure 1: Left: street view of the IZ-Rohstoffe; looking northeast the reader watches the southern and western front (long side). Right: longitudinal section; yellow-shaded frame indicates the Mineral Processing laboratories

The laboratories are equipped to experimentally cover all the main aspects of comminution, physical and physico-chemical separation techniques as well as agglomeration related to primary and secondary materials below a particle size of 40 mm. Samples of bigger particle size are prepared at selected crushing sites, sampled and transported to the lab. Depending on the units to be used in the technical center the maximum sample mass reaches 1000 kg (for vertical roller mill and electrostatic separator; maximum throughput rate mill 200 kg/h). The typical sample size, however, ranges from 20 to 50 kg.
The physical laboratories for ore characterization (incoming samples) and efficiency evaluation of separation processes (products of tests and technical processes) are designed to operate on average sample masses smaller than 5 kg. Apart from measuring size and specific surface, the main interest focuses on the evaluation of the distributions of physical properties of particle sets (like magnetic susceptibility, density and terminal velocity), the viscosity of slurries, optical microscopy in transmitted and reflected light and wet assays (especially iron). Automated mineralogy with respect to intergrowth analysis is done in cooperation with LKAB's research center in Malmberget. We receive the QEMSCAN raw data and evaluate them by image analysis software at the Chair.
Most of the flotation experiments are also performed at small scale of up to 2 l of suspension in order to search for the optimum reagents regime. A large collection of surfactants, frothers and activators help to solve scientific and industrial problems.
The general technical figures of the technical center and the labs are summarized in table 1.

The non-scientific staff comprises three members trained in physical testwork and a mechanic responsible for test rig construction, electrics and maintenance. The scientific development as well as the education on the apparatus of staff members and also students is mainly the responsibility of the author. This includes selection of methods and new equipment as well as calibration of measurement devices. The lab is open to use for all members of the Chair, who are trained in handling the apparatus and in the related safety affairs. Project partners are welcome to accompany the tests.

AREA, HEIGHT	**Processing technical center** 1. Dry comminution and sample preparation (h: 7.5 m) 2. Wet processing (h: 7.5 m) 3. Magnetic separation and agglomeration (3.2 m) 4. Drying (3.2 m) 5. Electrostatic separation (7.5 m)	200 m², h: 7.5 m and 150 m², h: 3.2 m
	Processing labs 1. Physical lab 2. Optical microscopy 3. Chemical lab and wet assay 4. Bentonite lab	166 m², h: 3.2 m
	Climate chamber 1 (electrostatic separation)	28 m², T: 20–60 °C
	Climate room (bentonite lab)	18 m², T: 20–30 °C
SUPPLY	Water	2.5 m³/h
	Gas (methane)	3.6 m³/h
	Pressurized air	6 bar
	Direct current	100 V, 10 A
	Alternating current	300 kVA
	Dedusting	500–1500 m³/h
	Travelling crane	load capacity 5000 kg
	Hoist	load capacity 6300 kg
	Sedimentation pool	11 m², 2.4 m³
	Sample storage	50 m³

Table 1: General technical data of the technical center and the labs

The challenge in operating a university laboratory is to provide both a fully equipped scientific laboratory with best suited measurement devices of defined accuracy and to educate our young students to make them future experts in mineral processing.

THE VISION

Every material intended for comminution and/or physical separation and/or agglomeration has its special features, providing the link to the unique technical process needed to obtain economically successful products. It needs the thorough understanding of intergrown phases locked in irregular shaped particles on one hand and the special behavior of the technical apparatus on the other in order to succeed in the operation of a technical comminution or separation process.
Careful experimental work thus forms the base at the beginning of all physical processing activities irrespective whether science, plant/apparatus design or plant/apparatus optimization of special raw materials are in the focus.
Apart from developing experimental methods, the main scientific idea behind the lab is to search for unambiguous figures to characterize the material as well as the machinery in order to understand their physical interaction with respect to processing. This should lead to physically based and technically reliable models for the prediction of the separation and comminution results and the selection and design of full scale equipment.
Although the Chair also operates equipment at pilot scale size, it is the general intention to use test rigs at the smallest scale possible that allows the physical modelling of the real scale process. The low amount of sample mass needed keeps measurements accurate and cheap, avoids cross-contamination of samples and intensive maintenance, helps to keep the tests safe and reduces efforts for environmental protection. Last but not least this allows accurate work within a reasonable time frame.

Apart from the scientific claim, the small scale tests allow a wide variation of parameters from which the most promising test conditions are selected to confine expensive pilot scale tests.

THE PERMANENT EQUIPMENT

The following section shall give a short overview over the main permanently installed test rigs as of September 2015. Additionally, a special area in the main hall is reserved for non-persistent test rig installations combining the permanent apparatus of the Chair with rented or borrowed units from industrial partners.

The technical center is equipped for dry comminution testwork with focus on the elaboration of the crushing and grinding characteristics of the material. As far as the stress conditions impact and compression are dominant, lab scale equipment is sufficient, whereas for compression and friction we had to change to pilot scale to simulate industrial conditions on a vertical roller mill. In all cases the scientific evaluation is based on the mechanical measurement of the energy input from grinding tools into the material via torque with the most suitable equipment. Special test routines combined with dispersity evaluation at analytical accuracy allow for comminution at highest energy efficiency. The energy and dispersity data thus are clearly defined and traceable in order to provide a reproducible base for ore characterization, intergrowth analysis and benchmarking of the efficiency of industrial comminution tools.

Screening and classification at pilot scale are done by a tumbling screen (Allgaier; particle size: –14 +0.063 mm), an air cross flow separator (CEMTEC; top cuts between 150 μm and 20 μm) and cyclone test rigs (40 μm to 2 μm cut-size).

The separation equipment at the technical center focuses on density separation as well as magnetic and electrical separation. Flotation at pilot scale recently started by the implementation of a flotation column.

There are jigs for sizes below 15 mm available as well as a drum separator for heavy media separation and a HMS cyclone test rig for feed size range between 8 mm and 0.5 mm in cooperation with VA Erzberg GmbH. Lab scale shaking tables and (ore) spirals at technical scale close the gap for density separation in the size range between 0.04 mm and 2 mm.

Magnetic separators for dry magnetic separation operate from low intensity (size range: –5 +0.04 mm; 0.01–0.08 T), variable intensity (two induction roll separators by Wedag and Carpco; –2 mm +0.1 mm; 0.1–1.8 T) and high intensity (IFE roll separator: 0.8 T; size range –8 mm +0.2 mm; IFE drum separator: 0.35 T; size range –20 mm +0.2 mm). Tests for wet low intensity magnetic separation can be committed with a lab scale Sala drum separator. Recently research work on a lab scale matrix separator in dry and wet mode including prototype development has begun.

The electrostatic free fall separator by Hamos with an electrode area of 2 m² is located in a special climate chamber for temperature and moisture control.

As the trend in mineral processing goes to ever more challenging raw materials (low grade and/or heavily intergrown ores, slags) that cannot be utilized in the fine state they have to be ground to for upgrading, research interest is also put on agglomeration. The lab is equipped with lab scale apparatus for binder research comprising an Eirich high shear mixer (10 l), pelletizing discs and drums (up to 0.62 m diameter), equipment for quality testing of the green pellets (e.g. porosity, water saturation) and a load cell for testing the compressive strength of green, dry and hardened pellets. A prototype of a down draft mini pellet pot (2 kg of pellets, temperature range from ambient to 1500 °C, electrical and gas power supply) for material testing of pellets at temperature conditions close to industrial rates was developed.

Tables 2 to 5 summarize the majority of the standard tests available. Nevertheless there are numerous additional test procedures that can be especially tailored to the needs of the customer to solve specific problems. A discussion with the scientists of the Chair of Mineral Processing helps to reveal the best fitting approach.

Figure 2: View into the physical lab (left); VRM 200 in the technical center (right)

		Test	Method		Sample Size	Grain Size
					[g]	[mm]
Material and Ore Characterization	Physical Ore Characterization (material as received)	Determination of bulk densitiy	Stamp volumeter Erweka SVM 202		dependent on maximum size	
		Particle size distribution	Allgaier screen, 1 m diameter, ATS 600/ 2		up to 50.000	- 16 + 0,060 mm
			Screen analysis **tests sieve shakers**, - UWL 400 Haver Boecker 600 x 600 mm screens (-100 + 8 mm) - Haver Boecker EML 200 mm screens (-6,3 + 0,04 mm)	test sieves	dependent on maximum size range	
			Manual Screen analysis dry (6300, ….,200, 160, 100, 71, 40,) and wet: (Rhewum system down to 25 µm)	DIN ISO 3310	500	
			air jet screen, Hosokawa A 200	dry	500	
			Lasergranulometriy (Mastersizer 2000, Malvern)	wet	50	-0,200 mm (- 1 mm)
			Sedigraph III (Micromeritics 5120)	wet	50	- 0,060 mm
			Andreasen Pipette	wet	10	- 0,040 mm
			Sedimentation column; physical size fractions below 25 µm for chemical analysis	wet	200	-0,040 mm
			Hosokawa, centrifugal air classifier, type 100 MZR	dry	1000	+ 0,005 - 0,100 mm
		breakage behaviour for intergrowth characterization	jaw crusher; Retsch BB 200			- 40 mm
			impact crusher, Hazemag 6286/60			- 40 mm
			laboratory rod mill (L:300 mm; D. 150 mm); rod charge: 7,5 kg; 1:2 Bond mill; batch tests		500 - 800	
			laboratory ball mill, torque rod for energy measurement; 200 mm x 200 mm, ball charge 8,5 kg		800 - 1000	feed 100% - 3,15 minimum product: 100% - 45 µm
			OCS method (development of the Institute of Mineral Processing; Prof. H.J. Steiner) stage wise energy "**O**ptimized **C**omminution **S**equence", (minimum energy expenditure to obtain a comminution product of a defined maximum size); reproducable, only material dependent particle size distributions results: natural breakage characteristic (material dependent "steepest" size distribution), calculated work index, Energy vs. Specific surface development (Rittinger grindability Index), particle shape factor, minimum size of comminution		usually 50 000 g; (- 40 mm) three stages consisting of 1) jaw crusher, 2)rod mill, 3) ball mill	
		Material density	He-pycnometer (AkkuPyk 1330)		50	up to 10 mm
			pycnometer, buoyancy methods			up to 100 mm
		density distribution (sink float analysis)	(liquids: 1 g/cm³ up to 4,5 g/cm³)		depending on size	- 15 mm
		Determination of the susceptibility and susceptibility distribution / preparation of mineralogical investigation	Davis Tube , Weda TRM		100	- 1 mm
			Pick up method (dry susceptibility distribution test: martitic ores, Böhm 2000)		100	- 1 + 0,1 mm
			Frantz Isodynamic Separator. Frantz L-1 (in size classes between - 1 mm + 0,04 mm)		20 per size class	- 0,71 + 0,04 mm
			Satmagan (outukumpu) Model 132, physical determination of magnetite content,		20	- 2 mm
		Determination of the Kozeny surface	Blaine apparatus		20	- 0,2 mm
			Permeran Outokumpu		20	- 2 mm
		Surface by gas adsorption	BET (porosity control), Flowsorb 2300 micromeritics, single point)		20	- 1 mm
		Chemistry in size classes	XRF (20 elements), Institute of Analytical Chemsitry, Montanuniversitaet		20	
		Wet assay for Fe2+, Fe3+	(for acid soluble ores, without pressure digestion)			
	Mineralogy	preparation of polished sections				
		Microscopy of polished sections	Reflected light microscopy (Reichert Polyvar®)			
		SEM EDX	Montanuniversitaet Leoben			
		X-Ray Diffraction	XRD, Montanuniversitaet Leoben			
		qemscan, data evaluation idiscover 3.1	cooperation with LKAB, Use of Qemscan equipment in Malmberget			

Table 2: Standard test procedures I: Ore characterization

Test			Method		Sample Size	Grain Size
					[g]	[mm]
grindability, Grinding Behavior	**Energy controlled grinding tests (dry),**		grinding values for material´s characterization, confirmation and comparison (no guarantees)			
	tumbling mills: Bond related tests, calculated work index		rod mill (100% < 6,3 to 100% < 1 mm; 0,2 mm; calculated work index)	0,3 x 0,15 m	5000 g/ 8 cycles	
	difference to Bond: smaller mills; measurement of energy by torque rods		Laboratory ball mill (energy mesurement by torque rod), surface development*)	0,2 x 0,2 m	8000 g/ 8 cycles	
	Elaboration of the surface development vs. Cumulative energy supplied		Laboratory ball mill especially used to find pelletizing fineness			
	roller mills:		VRM 200, see below, torque rod in the drive system		20.000 - 200.000 g	
			Zeisel tester		300 g/ 10 cycles	-1 + 0,7 mm feed
	roller mill VRM 200 CEMTEC with energy measurement by torque rod, and 3 modes of operation: Koller Gang, classic roller mill with internal air classsifier and bypass of coarse material of the classifier		roller mill, disc diameter 200 mm, average roller diameter 140 mm, 2 rolls, inetrnal air classifier 160 mm diameter, (300 - 4000 rpm); additional option: bypass of classifier coarse material		20 000 - 200 000 g/h	- 0,02 ; - 0,2 mm depending on settings of classifiwer
	Energy values for mill design: in cooperation with suppliers					
	classic BOND tests, rod and ball mill in cooperation with CEMTEC		Work index for mill design: only useful in cooperation with a mill supplier; valid for mill design, apparatus and process guarantee only by equipment supplier			
Green Pelletizing Tests	Pelletizing Tests	Pelletizing tests	0.63 m diameter pelletizing disc or drum; adjsutable speed		2.000 to 50.000	-0,2 mm
		Elaboration of optimum size distribution and water consumption				
		Variation of binder dosage and additives				
		Implementation of waste material				
	Quality Evaluation	Size distribution of Pellets				
		Moisture content in size classes				
		Drop test in size classes				
		Compressive strength: green and dry in size classes	Load cell			
		Porosity in size classes	GeoPyk 1360 (Micromeriitcs®)			
		Water saturation				
Induration Tests	Induration of dry pellets according to a temperature profile		Netzsch dilatometer furnace("single particle induration")			
			mini pellet pot; 2 kg pellets, temperature profile according to industrial plants, testing of binders and additives at varying temperatures, preparation of regular pot tests			
	Compressive strength of indurated pellets		Load cell, force and speed controlled; maximum looad 5000 N, messphysik			

*) calculated means: derivation of Bond´s index from measured energy values and size values. In Bond´s methods energy is not measured but depends on the strict apparatus setup. Our mills are not strict Bond mills

Table 3: Standard test procedures II: Grinding and agglomeration tests

Test			Method		Sample Size	Grain Size
					[g]	[mm]
bentonite characterization		Swelling index	(I.B.O FP-03/2003)			
		water adsorption, Enslin Neff - test	(I.B.O. FP-02/2003)			
		Methylene blue test	(VDG P35, I.B.O. 02/2003, I.B.O. 03/2003)			
		OCMA Test, viscosity	API SPec 13A/Iso 13500)			
		moisture content				
viscosity		Haake Rheostress 600 Rheowin VT 550 capillary visosimeter for suspensions				
permanent available SEPARATION equipment						
density separation	**+1mm**	laboratory drum tests up to 50 l heavy medium cyclon testrig, jig, Siebtechnik	cyclone: D6B-12 -839, 190 mm diameter, 18 - 30 m³/h volume stream, stirred sump		20.000 g 50.000 g	- 30 mm + 0,3 - 15 mm - 16 mm
	-1 mm	lab shaking tables spirals	1). 1 Krupp: K 1794 250 x 500 mm; 2).1 750 x 1000 mm 1 Krebs ore spiral, medium, 1 orginal Humphreys spiral		10.000 g	- 1 mm +0,04 mm - 2 mm +0,2 mm
Magnetic separation	**LIMS**	lab drum separator, adjustable field via coil current 0,005 - 0,06 T		dry	some 10.000	- 5 mm
		lab drum separator, SALA TU 1488/0 200 mm drum diameter		wet	some 10.000	- 1 mm
	HIMS	induction roll separators; Carpco MH (13) 111-5; 0,1 - 1 T		dry	some 10.000	- 2 mm + 0,1 mm
		induction roll separators WedAG i-1-150, 0,1 - 1,4 T		dry	some 10.000	- 2 mm + 0,1 mm
		permanent magnetic roll separator, roll diameter: 0,08 m; width: 0,25 m IFE KP 250-1, 0,7 T		dry	some 10.000	- 8 mm + 0,1 mm
		permanent magnetic drum sparator; 0,6 x 0,6 m, 0,35 T		dry		- 20 mm + 0,1 mm
		matrix separator		wet	depends on matrix type	
		research dry magnetic matrix separator				
electrostatic separation		lab scale roll separator, Carpco HP-167-M		Carpco	dry	- 20 kV
		EMS 500, free fall separator, climate chamber		Hamos	dry	- 100 kV
flotation		Denver D-1 lab cell, reagent testing	elaboration of reagent system in 1- 3 l cells			
		lab column cell: D = 80 mm; L = 2,5 m				
		Zeta potential measurement	streaming potential; EKA Anton Paar ; electrophoresis			

Table 4: Standard tests III: Bentonite testing and separation tests

Test		Method	Sample Size	Grain Size
			[g]	[mm]
drying	mini pellet pot test rig for down draft drying			
mixing	high intensity mixer, Eirich R 02 E, 5 l		< 10.000	- 5 mm
additional furnaces	tube furnace	used for heated permeated particle bed tests with off gas composition measurement		
	muffle furncae, Nabertherm L/15/12			
measurement systems	electrical power; off gas composition Testo 350 M (SO2, O2, CO, CO2, NOx),			
climate chambers	2 climate chambers/ rooms: 1. PA-OCA 71a-H/R 407150 m³; moisture: 10 - 60 %, Temperature: 5 - 60 °C;2. 32 m³, defined moisture for e.g. pelletizing tests			

Table 5: Additional equipment