ABSTRACT
As the mineral processing design and technology improved, especially in recent years, Turkey advanced fast forward in chrome beneficiation. With the impressive advent of the commodity prices in this decade, both established and entrepreneurial companies, domestic and foreign, have flocked to Turkey and have followed the iterative approach to perfect the processing equipment locally manufactured, aided by the establishment of separate mineral processing departments at established Turkish universities. This will continue unabated because the ore grades are declining, cost-cutting is prime goal and the innovative technologies can now handle fines. This paper presents in some detail this recent success story.

INTRODUCTION
Clearly one of the best inventions of mankind has been the ability to explore and identify the valuable minerals in the ground, dig them up, extract the valuable parts and get rid of the waste. Many of the enabling technologies, from producing pig iron in the blast furnace to copper floation using surfactants, have been instrumental in shaping our modern lives. And this impact will continue unabated in light of the wild gyrations in commodity prices, based on a foundation of the economic fundamentals of supply and demand. Within this context, mining and mineral processing constitute at an increasing rate the most important economic and industrial activities of our modern world. This is to be expected as the human population increases and a massive urbanization takes hold, making demands for lithium extraction to be used in mobile phones, steel to be used for bridges and construction and chromium to be added to iron and nickel and to make stainless steel kitchenware to be used by the newly urbanized populace. There was a dire prediction back in the 1970’s, published by the Club of Rome in their influential report called “The Limits to Growth,” the recent trends and data indicate that there is plenty of mineral resources, albeit with lower grades, requiring and making ore beneficiation a critical element in the supply chain of metals and minerals. For example, for chromium, an essential element for the making of stainless steel and more or less the inspiration for this paper, only about one third of the total 4.72 billion tonnes of the world’s deposits can be classified as rich grade, which makes mineral processing imperative.

THE BENEFICIATION
1.1 WHAT IS IT FOR?
Chromite beneficiation aka processing is required to enrich low grade ores, which is not economical to be sold under the market conditions. Currently market accepts +30% grade of chromite ore but at a very low price (open to fluctuation at 100 - 120 $/t FOB). Hence the most rational method in the utilization of poor-grade chrome is to be able to provide sufficient grade of chromium in the feed material as well as providing it in suitable form for efficient production, such as in the DC arc furnaces, which are gaining ground vis-à-vis AC furnaces used in ferrochrome production. Therefore, within the supply chain of the mining industry, ore beneficiation or mineral enrichment becomes the essential link between the Earth’s resources in the ground and a sellable commodity which can be used directly by a customer.

1.2 WHY IS IT NEEDED?
This is basically relying on the most basic principle of mineral processing, which is not to transport the waste minerals. When the ore is mined out at a low grade, to be able to extract the valuable from the waste, it needs to be processed in a distance as short as possible so that it can have a market and/or further processing value.

Of course the conventional wisdom is that beneficiation is more needed as the ore grade tools, and a push coming from the mineral industry to live up to its commitment to sustainability principles, hence spending more time and money in the planning, research and development and in the design and construction of the beneficiation plant, are helping the growing demands of the market.

1.3 WHAT IS CHROMITE CONCENTRATE FOR?
In the steel industry, chromite ore is used for ferrochromium production, which is another input for stainless steel production. A steel alloy which has a minimum of 10.5% chromium by mass is defined as stainless (inox) steel. Therefore, the stainless property of a steel comes from the ferrochromium and so from chromite ore itself. Chrome concentrate, which is ground to usually -1 mm particles, cannot be used directly in AC ferrochromium production furnaces. By the aid of new-tech DC furnaces, fine chromite can be consumed with no problem, as long as it is of high grade, at least 48%. Since concentrated chromite ore usually gives higher grade output on average grinding sizes, it makes this kind of process possible. This is not only the case for high carbon ferrochrome. The need for a higher grade chromium concentrate is even more essential in the making of low carbon ferrochrome.

Also, although currently Turkey has enough reserves to be able to precede production with lumpy ores through AC furnaces, in the future, with the depleting lumps and lower grade, processed, i.e., enriched low grades will be the only resource for ferrochromium production.
CONCENTRATE MARKET
Concentrate demands in recent years increased, and so did the prices. Since China established more DC furnaces, their purchase of concentrate has risen up drastically. They learned how to ship their specs and gained benefit from the uptick in the concentrate market. As a result and simply, concentrate production has become so important.

One thing that PGM producers discovered was that the chromite in the tailings after the platinum is extracted could actually be sold as chromite ore. These are UG2 Bushveld Complex ores where platinum could be found. Many South African companies did throw away their tailings although they contained already ground chromite which was ready for production. Once they discovered this case, they began extracting it. In fact, their chromite concentrate production costs were nearly zero to them. Only a few pumps and spirals were their capital and the overall operational costs. To be able to compete with “nearly free” UG2-sourced chromite ores, Turkey must improve the local technology to lower the costs of per-unit chromite concentrate. Competing with other concentrate producers around the world, Turkish companies definitely do need something, which is government’s support or sponsorship. It is a fact that when government eases the companies’ burden, the sector thrives. India and Oman are good examples of such government sponsorship helping concentrate production companies.

CHROMITE MINING
Although the country has some 70+ commodities being actively mined, Turkey still remains to be very much untapped and offers a large resource potential for an increasing number of global mining companies. The country’s mining industry in the past has lagged behind the manufacturing industry and contributed very little to the overall GDP. Since then, the Turkish government has recognized the importance of mining and has set a target to achieve some 5% of the GDP in 2023, the 100th anniversary of the Republic. Hence, the country, along with private investors and the government, is preparing Turkey to become a vibrant mining country. Apart from boron, chromite is Turkey’s largest metal product, followed by gold, bauxite and base metals. During the financial crisis in 2009, Turkey’s mining industry suffered a serious blow and then slowly recovered in 2010, continuing to 2011 with the global recovery and increased demand, primarily from China and the other growth markets.

CHROMITE PROCESSING
Of course there are several mineral processing techniques available to mining companies, like floatation, magnetic...
separation, etc., but the one used the most—and some of old-timer miners swear by it, saying it is the best suited for Turkish chromium-type ores—is gravity concentration. It is probably 2,000 years old and is now undergoing a renaissance of sorts, with the mineral and mining industry focusing on mineral separation and beneficiation as the chrome ore grade decreases and the volumes to be treated increase exponentially.

Gravity processing utilizes the natural g-force applied on the valuable and waste mineral. Water is presented in order to hinder the movement of material across distances due to gravity. In short, “chromite is separated from its waste according to their behavior inside water.”

Chromite processing requires suitable liberation size, defined by liberation tests applied to the ore. Several tests like optical counting, dense medium tests, etc., are available. When optimum size is determined, the feed material is crushed, ground to that size so that beneficiation can continue. Afterwards, jigs, dynawhirlpools, cones, spirals, shaking tables and centrifugal concentrators are used to recover chromite from the ground complex.

In gravity concentration, the efficiency of the process does not depend on the size of the particles as long as the mineral has been liberated from the rock. The other advantage of gravity concentration is that water is used as the medium, with no expensive reagents added. Setting up the concentration plant on a hillside provides the necessary acceleration force and the convenience of designing the concentration plant in 3, 4 or 5 levels as enrichment improves from top to bottom. In short, gravitational enrichment is cost-effective, uncomplicated, highly efficient and relatively easy to set up, hence the renaissance in gravity concentration plants due to all these reasons.

**PROCESSING IN TURKEY**

Turkey is a country where Alpine-type massive high grade chromite does exist. But since the reserves are dwindling, it has become unavoidable to start processing low grade ores and utilizing systems consuming fines as an input. Although this is a scenario which will play out in full force more in the near future, it is essential to prepare for this eventuality now. Therefore, beneficiation of low grade ores and the science and the practice of mineral processing of chromite ore have become important in Turkey.

Earlier, not even 20% grades of chromite were worth processing, but now, even 5% grade feed is considered rich enough to be processed. It is now possible to obtain 48% grade concentrate and 5% (today’s feed grade) tailings, with a 2.81:1 ratio (34.88% of feed as concentrate), from 20% grade feed. On the other hand, today’s 5% grade of feed would only give a concentrate with a ratio of 13.28:1 (7.53% of feed material), where the product is 48% and tailings are at 1.5%. Such a tailing grade like 1.5% is very hard to obtain under plant conditions and requires sophisticated instruments to constantly monitor and control the processing environment.

**KEF: A ROLE MODEL**

Early on, beneficiation of low grade ores was recognized, and one of the best examples of such a modern concentration plant was erected at Kef, Elazığ, with an 84 tph capacity. The factory was established in 1991, since the dry processing plant was not performing properly. The

![Figure 2 - Annual concentrate production of ETI KROM. Note the expected revisions projects completed at Kayseri and Iskenderun in 2014, and in 2015, Adana Project will be engaged to production](image-url)
Plant was entirely designed and set up by a Finnish company. Some Turkish staff was trained only for a few days in the parent company’s factory abroad, and then it switched on. A plethora of problems ensued during the commencement of the operations. It was just because plant operators simply didn’t know what to do, how to adapt the processing plant according to the fluctuations in the feed grades. During the sampling phase, the most important stage where everything actually begins to be able to set up the plant, the sample feed ore was washed, “polished” and sent to Finland in a manner of showing off that “Even Turkey’s low grade is not that low.” (Sampling must be properly done to be able to represent the whole mass of ores that will be processed. There is no reason to clean up the sample before putting it into analysis. In fact, cleaning up the sample defies the purpose of sampling). When you check the project parameters, you can see that the average feed grade is expected around 32%, which means the plant cannot process grades below 32% efficiently. Concentrate grade was targeted to 42%. Old plant tailings were around 20%. When the recovery was calculated, it was possible to see a value around 71%, which sounds good. But the truth of the matter was a different thing indeed. Average feed grades were not going above 25% and so the recovery plummeted down to 49% and even further.

One of the main problems of the plant was that it was modeled after the existing plants operated in the company’s country, designed according to the geography and topography of the native flat landscape. Inordinate amount of leveling was done to make the hilly landscape more flat instead of using the oldest force of separation referred to above, gravity. This resulted in using some 30 slurry pumps continuously circulating the pulp inside the plant instead of the 9 or 10 needed if the slope could have been used with natural flow. This resulted in an undue increase in operational costs.

After the privatization of ETİ KROM A.Ş., a transformational change took place, and not only in the day-to-day operations. The whole plant was re-plumbed, re-wired and adapted to the very specifics of the feed, the environment, and the available engineering know-how. As a result, dramatic results were obtained and the improvements were noticeable. For example, even a minimum 11% feed grade could be fed to the plant and the recovery increased to 66%. Further improvements are constantly being made and the current project is focused on finer particles achieving a final recovery circa 75% and a grade around 48%, but still, market demand and constraints are important for production amounts.

**KNOWLEDGE IN TURKEY**

With the dramatic rise of commodity prices in the 2000’s, coupled with the more liberal attitude of the Turkish government in granting concession rights to the private sector, many domestic and foreign mining companies have shown a keen interest in exploring, mining and building beneficiation plants in Turkey. Not only has the expertise in mineral beneficiation improved, but so has the expertise of the equipment suppliers, automation engineers, process engineers, safety and environmental engineers.

There are two types of concentrate plants being built in Turkey, which are the slovenly ones and the ones with proper infrastructure. From small to large companies, more entrepreneurial fervor has caught fire and many miners and non-miners have now built their own concentration plants. Many of these plants are located in the

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**Mining Turkey**

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well-known regions like Bursa - Orhaneli, Adana - Aladağ, Eskişehir - Kavak and Elazığ - Guleman. Turkish companies are now capable of designing and building their own processing plants with their own and/or contracted engineering teams. Even mineral processing engineering has become a sub-branch on its own and a few of the universities, amongst them Istanbul Technical University, Hacettepe and others, have founded separate departments with research cadres performing truly world-class research, serving many of the local mining companies. Many mineral processing engineers have entered into the mining engineering market, and they are capable of planning the whole plant, the beneficiation process flow, and any of them, including females, are now running whole shifts or entire factories. With the estimates running around that only 40% of the mineral riches of Turkey have now been and/or are actively mined, the advent of mineral processing in Turkey will continue many years into the future.

MADE IN TURKEY

There is a huge increase in the number of local suppliers compared to, say, ten years ago, not only in terms of equipment for chrome processing but in all sectors of mineral processing. Most of these companies are small in scale, primarily manufacturing customized gear for the processing industries, and are primarily located in the Organized Industrial Zones (OIZ) near the bigger cities in mining regions. Companies from Yıldırım - Bursa, Çayırova - Kocaeli, Tuzla - Istanbul, Mediriköy - İstanbul and Ostim - Ankara can produce many types of mineral processing equipment and their spare parts, like rod mills, ball mills, screens, polyurethane spares, pumps, pump liners, mill liners, hydrocyclones, shaking tables, spirals and many more. With these local options available, mineral processing plant erection and machinery costs can go down substantially. For instance, an official quotation for a mineral processing plant project around 110 million euro can easily go down to 60 million euro with a Turkish brand.

Just in case of a misunderstanding; these companies are not sweatshop producers but pioneers of Turkey.

PROCESSING TECHNOLOGIES

Today’s chrome processing technology is nothing new and exploits the relative movement in response to gravity to separate the mineral from the dirt. For many years, the basic design of the equipment and the process flow has not changed much dramatically, but a better quantifiable understanding of the concentration processes has resulted in incremental changes. The proliferation of many entries into this field has produced a fast learning environment, with prototype production followed by testing it with a certain type of ore-experimenting-copying-altering, and producing the final product by the well-known iterative innovation cycle. Still, there is some rather new equipment available. All these methods below are available in our country and are being used to recover chromite in Turkish processing plants.

MGS (MULTI GRAVITY SEPARATOR): This is modeled after a shaking table in action. Shaking table can only utilize the g-force which naturally comes down towards the earth. But when the shaking table rolls on itself and attaches at the ends, one ends up with a multi gravity separator. This cylinder rotates at a speed generating a centrifugal force, and so another g-force is now created. The revolution speed allows one to control the force, which is actually constant for the shaking table. MGS can be used for fine particles below 200µ to 10µ at a 55% max recovery performance. To get rid of -10µ, MGS must be utilized with a hydrocyclone group (usually mushroom type).

CENTRIFUGAL CONCENTRATORS: This semi-continuous (batch) concentrator is a specially designed fluidized centrifuge that separates heavy material, such as gold and platinum, from lighter background material such as quartz. The material must be ground to an appropriate size, mixed with water, and then fed into the machine. Equipment is generally applied to materials in which the heavy component to be recovered is a very small fraction of the total material. For most primary applications the grade of the heavy material will be less than 500 grams/ton (0.05% by weight).

CENTRIFUGAL JIG: Yet another centrifugal concentrator, but this time it is a jiggling machine that’s rolled. It is used with a screen for collecting ragging materials (usually metal balls with proper density). Processing can go down to 10µ.

Apart from this rather new technology, many modified shaking tables (e.g. zigzag) and many kinds of spirals utilized for different ore types are both used and produced in Turkey by totally domestic companies. Furthermore, some concentrator plants are capable of producing their own equipment, totally customized to suit their own needs.

CONCLUSION

In recent times, Turkey performed very well and excelled in the chrome concentration branch of mineral processing, with the know-how in the design, engineering and equipment improved immensely, following a reiterative method commonly seen in innovation models. There are chrome processing plants available for processing 7% feed grade at a capacity of 4000x2 tpd, which is world class. Turkish universities are graduating good engineers with an engineering degree in mineral processing. The Turkish government’s focus on mining to improve its share in the overall country’s GDP is also encouraging for more exploration, assaying, and for both established and entrepreneurial companies to start mining ventures, especially in chrome. Many local companies are producing high quality machinery that can now compete with their foreign competitors. “A new era in Turkish chrome processing is under way, guided by Turkish engineers…”

REFERENCES


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