

1. Production and use of potassium chloride

Potassium chloride accounts for most of the K used in world agriculture. It represents 96% of the world potash capacity, the balance of 4% is potassium sulphate (K_2SO_4), potassium nitrate (KNO_3) and potassium-magnesium salts (Prud'Homme, 1997). The K content of KCl fertilizer is frequently expressed on the basis of its oxide equivalent (K_2O), although some countries use the element K. Commercial KCl fertilizers contain between 60-62% K_2O - the large K content of all the K fertilizers.

1.1. Mining

Potassium bearing minerals are mined from underground ore deposits, salt lakes and brines (Plates 1.1 and 1.2). The most abundant mineral in commercial deposits is sylvite (KCl). Sylvite and halite (NaCl) form the common ore called sylvinite (Garret, 1996). Kainite ores ($4KCl \bullet 4MgSO_4 \bullet 11H_2O$) are much less common. In brines, carnallite ($KCl \bullet Mg Cl_2 \bullet 6H_2O$) is present with halite (Eatock, 1985).

Two methods are used to recover K from underground ore bodies: (1) conventional shaft mining and (2) solution mining. Most mines (eg. Canada, FSU¹, Spain) are serviced by vertical shafts about 5 m in diameter and from 900 m to 1100 m deep. The deposits are mined by electrically operated machines and conveyed to the surface where it is crushed and processed (Eatock, 1985; Garret, 1996).

Solution mining is used when the ore body is too deep for economical mining by conventional methods. The world's first solution mine is near Regina (Saskatchewan, Canada) where the ore was approximately 1500 m deep. The process consists of drilling into the ore body by injecting water and recycled spent water steams to dissolve the salts. The resultant brine is pumped to the surface and treated in evaporators to recover the NaCl and increase the KCl concentration to the saturation point. The saturated brine is then treated by a crystallization process to recover the K (Eatock, 1985).

Potassium chloride and other salts are also produced from naturally occurring brines from the Dead Sea in Israel and Jordan, from the Great Salt Lake in USA, and from the Salar de Atacama in Chile (Garret, 1996). At the Dead Sea, the process consists in charging evaporation pans with brine from the sea. Natural evaporation concentrates the solution and most of the NaCl is precipitated. The concentrated brine is then pumped into a second series of open pans, where carnallite settles naturally to the bottom. Special harvesters dredge the ponds and pump the carnallite directly to the refineries, where flotation and crystallization methods are used to recover the potash (Garret, 1996).

¹ FSU: Former Soviet Union

1.2. Production

Total world K₂O production in 1998 was 25.870 Mt, most of it as KCl (Prud'Homme, 2000). KCl is produced at present in 12 countries (Table 1.1), of which seven account for 90% of the world production. The largest production is in Canada (35.5%); followed by Germany (13.8%), Russia (13.5%), Belarus (13.1%), Israel (6.4%), USA (5.0%) and Jordan (3.5%).

Table 1.1. K₂O production by countries in 1998.

Country	Production	
	(Mt K ₂ O)	(%)
1. Canada	9.195	35.5
2. Germany	3.582	13.8
3. Russia	3.500	13.5
4. Belarus	3.400	13.1
5. Israel	1.668	6.4
6. USA	1.300	5.0
7. Jordan	0.916	3.5
8. UK	0.608	2.4
9. Spain	0.497	1.9
10. France	0.417	1.6
11. Brazil	0.327	1.3
12. Chile	0.280	1.1
13. Others	0.180	0.7
WORLD	25.870	100

Source: Prud'Homme (2000).

World K₂O production capacity is estimated at 35 Mt, thus only about 70% of world capacity is utilized. The largest not fully operated deposits are located in Canada and FSU.

1.3. Consumption

The total world consumption² of K₂O in 1999 was 24.648 Mt (Table 1.2). USA is the main consumer, with 20.7% of world total consumption followed by China (13.6%), Brazil (9.3%), India (7.2%) and France (6.2%) (IFA, 2000).

² "Consumption" is calculated as imports+home deliveries of countries producing potassium fertilizer. Therefore it does not reflect its direct use as fertilizer in agriculture, as part of the production is used for granulation processes and then exported.

Table 1.2. Major K₂O consuming countries in 1999.

Country	Consumption	
	(Mt K ₂ O)	(%)
1. USA	5.107	20.7
2. China	3.360	13.6
3. Brazil	2.281	9.3
4. India	1.770	7.2
5. France	1.521	6.2
6. Others	10.609	43.0
WORLD	24.648	100

Source: IFA (2000).

North America was also the main consumer by region in 1999 (Table 1.3), accounting for 22.5% of world K₂O consumption, followed by West Europe (19.8%), Asia (17.3%), Socialist Asia³ (14.5%) Latin America (12.7%), and FSU (5.6%) (IFA, 2000).

Table 1.3. K₂O consumption by regions in 1999.

Region	Consumption	
	(Mt K ₂ O)	(%)
North America	5.534	22.5
West Europe	4.875	19.8
Asia	4.243	17.3
Socialist Asia ^{a)}	3.572	14.5
Latin America	3.129	12.7
FSU ^{b)}	1.382	5.6
Central Europe	0.690	2.8
Middle East	0.504	2.1
Africa	0.321	1.3
Oceania	0.318	1.3

^{a)} 95% is in China

^{b)} FSU: Former Soviet Union

Source: IFA (2000).

Potassium consumption by developed and developing countries from 1960 to 1998 in Table 1.4 shows that in 1960 the developed countries (West Europe, North America, Oceania, East Europe, FSU, South Africa and Japan) consumed 94 % of the total production. Between 1980 and 1990 K₂O consumption in the developed countries tended to stabilize, reflecting relatively high rates of KCl

³ China consumption represents 95% of Socialist Asia.

application. Between 1989 and 1995 consumption fell sharply, mainly due to the large decreases in the former communist-led countries of Central and East Europe and the FSU. As a result, consumption in the developed countries declined by about a half, from 21.21 Mt in 1988/89 to only 11.80 Mt K₂O in 1994/95.

Table 1.4. K₂O consumption in developed and developing countries during 1960-1999.

Year	Consumption (Mt K ₂ O year ⁻¹)		Relative consumption of developing countries
	Developed countries	Developing countries	(%)
1960/71	7.96	0.52	6.1
1970/71	14.85	1.44	8.8
1980/81	20.22	4.17	17.1
1990/91	17.47	7.14	29.0
1991/92	16.19	7.53	31.7
1992/93	13.84	6.67	32.5
1993/94	12.44	6.63	34.8
1994/95	11.80	8.07	40.6
1995/96	11.95	8.60	41.8
1996/97	12.06	8.67	41.8
1997/98	12.09	10.33	46.1
1998/99	11.44	10.54	48.0

Source: IFA (2000).

During the later years of the 1990s, K₂O consumption of developed countries has stabilized, while that of developing countries has continued to increase to reach in 1999 about 48% of the world total, compared with only 6% in 1960/61 (IFA, 2000).

1.4. Usage by crops

Potassium application to different crop species is shown in Table 1.5 (Harris, 1998). The largest use is on cereals which get about 50% of the total used, followed by oilseeds (16%). After cereals and oilseeds, the usage is relatively evenly split between vegetables, sugar crops, root and tubers and fiber crops. The largest proportion of total consumption used on cereals is because of the vast area grown annually, however, the average use per hectare is small, 12 kg K₂O ha⁻¹. The amount applied to sugarbeet and sugarcane (65 kg K₂O ha⁻¹), root and tubers crops (53 kg K₂O ha⁻¹) and to vegetables (46 kg K₂O ha⁻¹) are much larger, because these crops have a large K requirement for high yields and quality.

Table 1.5. World K₂O use by crop types.

Crop type	Potash use (Mt K ₂ O)	Area (M ha)	Application rate (kg K ₂ O ha ⁻¹)
Cereals	7.029	601.9	12
Oilseed	2.383	102.6	23
Vegetables	0.898	19.2	46
Sugar beet/cane	1.338	20.5	65
Root and tubers	1.073	20.2	53
Fiber	0.375	29.6	13
Fruits	0.848	21.3	40
Tobacco/stimulants	0.575	11.8	49
Pulses	0.265	42.7	6
TOTAL	14.786	869.8	17

Source: Harris (1998).

In each country the largest proportion of K goes to the crops covering the largest area, rice in China and India, maize in USA and grassland in France (IFA-IFDC-FAO, 1999).

1.5. Grades of potassium chloride

Grades of KCl are defined by their K₂O content and particle size. Agricultural grades are those with 40-60% K₂O, and industrial grades are > 62%. KCl is produced in five agricultural decreasing grades (Table 1.6; Plate 1.3): Granular, Coarse, Standard, Fine and Soluble, in order of the particle size. A sixth product called industrial or chemical grade, is a material of high purity and manufactured only by a few producers in the world. Over three quarters of the K₂O consumed in North America is as coarse and granular KCl (Garret, 1996) while in other regions the main grades are standard and fine.

Table 1.6. Nominal U.S. KCl specifications by particle size and K₂O content.

Name	Nominal particle (mesh)	Size range (mm)	K ₂ O content (%)
Granular	6- 20	0.841-3.36	60
Coarse	8- 28	0.595-2.38	60
Standard	14- 65	0.210-1.19	60
Fine	35-150	0.105-0.420	60
Soluble/Suspension	35-150	0.105-0.420	62
Chemical	-	-	63

Source: UNIDO-IFDC (1998).

- Granular and coarse grade KCl: is suitable for direct application as a single nutrient (K) fertilizer, or as a component in mechanically mixed blends (bulk blending) that contain other granular fertilizers (diammonium phosphate, urea, etc).
- Standard grade KCl: the relatively large crystals make it suitable for direct mechanical or manual application, because it is not blown away by the wind. It is often used by farmers for hand mixing with other fertilizers in the field and is also used in granulation processing for the production of PK, NK and NPK compound fertilizers.
- Fine grade KCl: is used as a raw material in granulation processes for production of NPK fertilizers and for the industrial production of K_2SO_4 . Fine material can be either white or pink/red in color.
- Soluble grade KCl: is white and is used as a raw material in the industrial production of clear liquid and suspension solution fertilizers. Owing to its small particle size and fast dissolution, it is used by the industry as a single element fertilizer solution (0-0-15) or a multi-element solution with other fully soluble fertilizers. It is also used for the industrial production of K_2SO_4 .

KCl can vary in color from deep red to white, the color coming from contamination with minor amounts of iron oxides that are occluded in the crystals of the sylvinitic ores (Stewart, 1985). KCl derived from brines or from solution mining is white. There is no difference in the behaviour of the red and white forms in the soil.

Two undesirable properties of KCl are: (1) its tendency to cake and (2) dust formation which results from crystal breakage during handling and shipping. Therefore, agricultural grades are usually treated with additives (amines and oils) before shipping to improve their handling characteristics and to reduce caking and dusting (Eatock, 1985). When such additives are not wanted because of specific industrial demands, a drier and closely sized product (special grades) is shipped (UNIDO-IFDC, 1998).

1.6. Formulated fertilizers with potassium chloride

1.6.1. Bulk blended mixtures

Granular KCl is often applied in mixtures with other fertilizers to provide, in one application, the nutrient requirements of the crop.

The process of KCl granulation starts with compaction, which is a dry agglomeration process, between two counter rotating rolls. First, the small crystals of KCl are forced between the rolls compacting them into a coherent, sheet-like material (flake). Then, in the granulation section, the flakes are dry-milled to a prescribed size distribution by crushing and screening. The finishing section includes a polishing unit, a coating unit and final product storage facilities (UNIDO-IFDC, 1998). Granulated of KCl is

now an important part of world-wide KCl use; currently, about 40% of the total world capacity production is granulated (UNIDO-IFDC, 1998).

Bulk blends are dry, mixed granular sized fertilizers. Farmers can mix the different component fertilizers themselves, or purchase blends appropriate to their needs from dealers who operate bulk blending equipment. Bulk blending is popular because the product allows a flexible combination of nutrients at different NPK ratios and the use of different types of fertilizers. The investment cost of a bulk blending plant is much less than that of a granulation plant (IFDC, 1989).

Bulk blending accounted for 19% of world K consumption in 1993 (IFA, 1992). Bulk blending has increased significantly between 1990 and 1999, especially in Latin America, Europe and Asia. In the USA, 60% of total use of K is in bulk-blended mixtures (Garret, 1996).

The most common components used for bulk blending with granular KCl are diammonium phosphate (DAP), urea (prills or granular), ammonium nitrate (AN), triple superphosphate (TSP) and various N-P-K-Mg granulated products. KCl is very suitable for blending because it is compatible with most commonly available fertilizers (Table 1.7). When blending more than two fertilizers, problems can arise due to chemical incompatibility (generally high hygroscopicity). For example, a mixture of TSP, urea and KCl will cake during storage into hard lumps. This is because TSP reacts with urea, releasing water and wetting the mixture, which then cakes on drying.

Table 1.7. The compatibility of KCl with other fertilizers.

KCl + Fertilizers:	Compatibility ^{a)}
<i>Nitrogen</i>	
Calcium nitrate	C
Ammonium sulphate	C
Ammonium sulphate nitrate	LC
Urea	LC
Calcium cyanamide	LC
<i>Phosphorus</i>	
Superphosphate, triple super phosphate	C
Diammonium phosphate	C
Basic slag	C
Rock phosphate	C
<i>Potassium</i>	
Potassium sulphate	C
K-Mg sulphate	C

^{a)} C: compatible; LC: limited compatibility

Source: IFA (1992).

Other blends such as ammonium sulphate, TSP and KCl can be blended and stored without any problems (Achorn and Balay, 1985).

Dry blended granular materials tend to segregate into different sizes if the size distribution of the raw materials is not suitably matched. To prevent segregation, the components of a blend should be in granular or coarse form, and have similar particle size distribution (Achorn and Balay, 1985).

1.6.2. Compound fertilizers

Standard and fine grades of KCl can be used as a K source for NK, PK and NPK fertilizers in the form of granulated products. Two major processes are used to produce granular products: the agglomeration type process and the accretion type. In most of the granular NPK products, the agglomeration process is used. The process is fed mainly with dry, small particle sized solids (such as fine grade KCl) which are assembled into agglomerates by mechanical force and cementing agents (UNIDO-IFDC, 1998).

1.6.3. Fluid fertilizers

KCl is the principal source of K in fluid fertilizers, because it is the most soluble and least cost of the major K sources. Fluid fertilizers are available as suspensions and as clear liquid fertilizers.

1.6.3.1. Suspension fertilizers

"Suspension fertilizers" are fluid fertilizers that contain nutrients in solution and suspended as fine particles (Wolf *et al.*, 1985). The particles remain suspended, because clay is added to the suspension to increase its viscosity (Potts, 1984).

Suspension fertilizers have higher nutrient concentrations than clear liquid fertilizers because the solubility of materials is not a limiting factor. The main disadvantage of suspensions is that they contain solids that can clog emitters (Potts, 1984). Therefore suspensions cannot be applied through microirrigation systems.

Suspension fertilizers with up to 30% K₂O may be made with KCl when attapulgite clay or other suspending agents are used to keep the crystals in suspension (Wolf *et al.*, 1985). NPK suspensions of different grades (4-12-24⁴, 15-15-15, 5-15-30, 10-20-20, etc.) can be produced by fluid blenders (Wolf *et al.*, 1985). Potts (1984) described detailed preparations of NPK suspensions.

⁴ NPK content in fertilizers is expressed as % N - % P₂O₅ - % K₂O

1.6.3.2. Clear liquid fertilizers

"Clear liquid fertilizers" or "solutions" are fluid fertilizers in which all nutrients have been dissolved in solution (Wolf *et al.*, 1985). Solution fertilizers are specially well adapted to application through microirrigation systems (see Chapter 5).

Dissolution of KCl can give saturated solutions with 14.9% K₂O at 10°C (Wolf *et al.*, 1985). NPK solutions are prepared in liquid fertilizer mix plants at different grade and NPK ratios; for example 1:2:2 (5-10-10), 3:2:1 (12-8-4) (Wolf *et al.*, 1985).

The farmer can also mix fertilizers in the field and prepare liquid NPK stock solutions with relatively low nutrient concentration, and then apply them through the irrigation system (fertigation). Clear NK, PK and NPK fertilizer solutions with maximum 10-15% of total nutrients (N, P₂O₅ and K₂O) can be easily prepared with initial temperatures of 10°C, based on urea, phosphoric acid and KCl with minimal mixing (Lupin *et al.*, 1996).

1.7. Other uses of potassium chloride

1.7.1. Deicer

Potassium chloride is used as a deicer for clearing snow and ice from roads, drives, and the entries to buildings. Other chemicals used as ice melters are: rock salt (NaCl), calcium chloride, magnesium chloride, calcium magnesium acetate and urea. The best product in terms of limiting corrosion is the acetate, but it is effective only down to -6-7°C. Potassium chloride is effective down to -11°C, lower than the other Cl salts and urea, and is equally corrosive to metals, but does not chemically attack concrete. The main advantages of KCl over the other melting materials are: (1) it does not contain Na, and (2) the K has a fertilizing value for grass, trees and shrubs on the roadside.

1.7.2. Water softeners

Potassium chloride is used to regenerate the ion exchange resins used to treat hard waters, working on the principle of ion exchange. A synthetic resin bed (zeolite) is charged with Na or K ions by regeneration with NaCl or KCl. Calcium and Mg in the hard water exchange with the Na or K to give soft water, free from Ca and Mg. In addition, Fe and Mn, which are contaminants in drinking waters, can be removed by the same process.

Using KCl rather than NaCl is more environmentally friendly (Avnimelech *et al.*, 1992). This is because the size of the hydrated K ion is 40% smaller than that of the hydrated Na ion so the K ion is more effective at exchanging with Ca and Mg. Thus less KCl has to be used and so less Cl is discharged to

the environment. KCl can reduce the amount of chlorides discharged to septic or sewage systems by as much as 20% (Rebhurn and Shechter, 1966).

1.7.3. Industrial uses

About 4-5% of potash production is used in industrial applications (UNIDO-IFDC, 1998). In 1996, the world supply of industrial grade potash was close to 1.35 Mt K_2O . This industrial material is 98-99% pure, compared with the agricultural potash specification of 60% K_2O minimum (equivalent to 95% KCl). Industrial potash should contain at least 62% K_2O and have very low levels of Na, Mg, Ca, SO_4 and Br (Table 1.8). This high-grade potash is produced by only a few producers in worldwide.

Table 1.8. Industrial grade potash analysis.

Component	Unit	Standard content
KCl	%	>99.90
K_2O	%	>63.12
H_2O (at 105°C)	%	<0.07
H_2O (at 700°C)	%	<0.67
Water insolubles	mg kg^{-1}	<75
Acid insolubles	mg kg^{-1}	<75
Sodium	mg kg^{-1}	<150
Bromine	mg kg^{-1}	<700
Sulphate	mg kg^{-1}	<10
Calcium	mg kg^{-1}	<10
Calcium and magnesium	mg kg^{-1}	<30
Iron	mg kg^{-1}	<5
Lead	mg kg^{-1}	<3
Copper	mg kg^{-1}	<0.5
Nickel	mg kg^{-1}	<0.5
Chromium	mg kg^{-1}	<0.1
Molybdenum	mg kg^{-1}	<0.1
Vanadium	mg kg^{-1}	<0.1
Titanium	mg kg^{-1}	nil

Source: UNIDO-IFDC (1998).

Potassium hydroxide (KOH), also known as caustic potash, is the largest-volume K product for non-fertilizer use. It is produced by the electrolysis of industrial KCl and is widely used for manufacturing soaps, detergents, grease, catalysts, synthetic rubber, matches, dyes and insecticides. Caustic potash is also as a liquid fertilizer and as an ingredient in alkaline batteries and photographic film processing chemicals.

Potassium hydroxide is a raw material in the production of various K salts, mainly K carbonates, and also citrates, silicates, acetates, etc. Potassium carbonate confers excellent clarity to glass thus is used for most fine optical lenses, eyeglasses, fine crystal, glassware, chinaware and TV tubes. Potassium bicarbonate is used largely in the food and pharmaceutical industries.

Potash-derived compounds and salts are also used in the production of metal fluxes, cured meats, tempered steel, paper fumigants, case hardened steel, bleaching agents, baking powder, cream of tartar and beverages.

Worldwide, industrial KCl is estimated to be used as follows: detergents and soaps, 30-35%; glass and ceramics, 25-28%; textiles and dyes 20-22%; chemicals and drugs, 13-15%; and other uses, 7-5% (UNIDO-IFDC, 1998).

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