MOBILITY IN MUD

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Abstract

The Vaudreuil Alumina plants use deep thickeners to prepare their red mud for disposal in a 60 ft. High wet stack.

Management of this stack requires four-seasons access to the pipework, and occasional dust suppression procedures. From peak to foothills the stack can display all the phases of fluidity present in the mud.

Vaudreuil has developed a family of vehicles to provide the required access from a 25 tonne amphibian to spead gypsum on the mud to control dusting, to a 1.5 tonne tractor-trailer for personnel transport.

This paper describes the units in detail, and explains how the characteristics of the mud can be used to give a good load-bearing capacity.

Introduction

In 1987, Alcan Smelters and Chemicals Ltd. started a new red mud stacking process (photo 1). With the addition of synthetic flocculants, the red mud is thickened to a higher percentage of solids. This enables it to be piled instead of poured into the settling ponds.

The access to the mud pile becomes a problem when the mud, which is dumped from one central location, expands over a large surface. The maintenance of the site requires taking readings, making repairs on the piping system and controlling dust generation; these tasks can only be carried out in the winter when the surface of the pile is frozen.

Stacked Red Mud

Characteristics. The age of the stacked mud has an impact on its load bearing capacity. During draw-off, the density of the mud varies from 1.2 to 1.5 with solids consistency of 50%, reaching 70% after drying. Extremely fine mud remains at the bottom of the slope and is covered with water run-off. At the top, the segregation of solid particles offers a better load bearing capacity. There is a wide range of viscosity from the top to the bottom of the stack.

This viscous mud is similar to clay and offers a very good resistance to movement. Furthermore, its thyxotropic character (i.e. it liquefies after mixing) prevents any kind of traction with wheels or tracks.

Drying. In the drying stage, a thin crust is formed at the surface. It offers a load-bearing capacity in the order of 35 kPa (5 lb/in^2) which enables circulation of vehicles. This load-bearing capacity is made possible by the lower viscous mud layers supporting the crust. When a load is applied, the crust loses its shape its elastic limitations should not be exceeded or else the vehicle will get stuck.

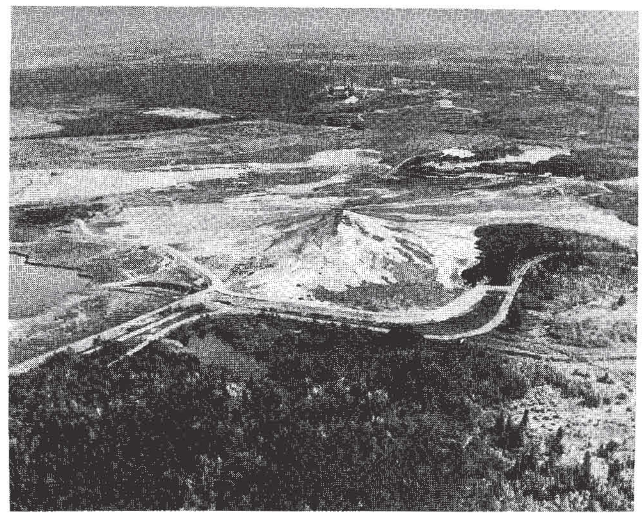


Photo 1
Red Mud Stacking

Mobility

In June 1991 a development program aimed at discovering methods to move a vehicle on the mud stack was undertaken. This program covered the production of light-weight vehicles for the transportation of personnel, as well as a 25 ton vehicle for the transportation of material.

The first criteria to consider during design is safety, therefore, all the vehicles which were developed are amphibian. The weather conditions at the Vaudreuil plant are extreme and must be considered. The temperature varies daily from +10 C to -35 C and is frequently associated with winds of 70 km/hr in winter. Furthermore, the access roads to the site are built at the top of the peripheric retaining mud dikes. The narrow width and steepness of the dikes require that the vehicle be very easy to handle.

The ARGO

In June 1991, the first trials were carried out with an amphibian tracked vehicle, the ARGO (photo 2). This vehicle has a ground pressure of 4.6 kPa (0.67 lb/in^2) and weighs 590 kg (1300 lbs). Trials showed that this vehicle which has low load-bearing capacity does not break the dried mud layer (crust) but because this crust is not homogeneous, the vehicle gets stuck frequently. When stuck, it sinks into the surface down to its waterline. The vehicle shell which is immersed in the mud then offers very good resistance to movement, and the traction of the tracks cannot overcome.

The skating of the tracks amplifies the traction problem since the thyxotropic mud turns to liquid, therefore leading to a total loss of traction.

Photo 2
Argo Magnum 8 x 8

Results

This vehicle is very safe because of its amphibian character, but it is not very reliable since it can get stuck frequently.

These trials allowed the analysis of the various load-bearing capacity and viscosity phases of the mud in which the vehicle must operate.

Technical Data

Cost : $10,000.00 US

'ARGO' 8 MAGNUM:

Engine:	Kohler magnum, 4 stroke, 18 HP.
Brakes:	Hydraulic disk brakes
Speed:	Ground: 29 km/h (18 mph) On water: 3 km/h (3 mph)
Number of passengers/weight:	On ground: 6 persons or 454 kg (1000 lb.) On water: 4 persons
Pressure to the ground (maximum weight):	Tires: 14.5 kPa (2.1 lb/in²) Tracks: 4.6 kPa (0.67 lb/in²)
Weight of the vehicle:	520 kg (1300 lb.)
Tires:	'Runamuk' 20 x 11 x 008 NHS
Frame:	High density polyethylene
Chassis:	Steel girders
Steering:	Tracks blocked with brakes ("Skid-Steer").
ARGO:	Trademark of Ontario Drive and Gear Company, manufacturer of traction-tracked amphibian vehicles

THE AERO ARGO

In September 1991, a skirt formed with segmented fingers (photo 3) was added to the ARGO to improve traction in viscous mud. The objective of the air pressure thus created is to clear the vehicle from the mud, thereby reducing considerably the resistance to the forward movement. In the mud, the skirt system creates a pressure of 0.77 kPa (80 mm H_2O) which is equivalent to the 80 mm displacement of mud under the vehicle.

The design of the segments requires that the tracks sink by 2 inches into the mud in order to allow the air cushion to operate. The lower face of the tracks remain in contact with the mud and it is then possible to take advantage of the viscosity of the mud in order to achieve a proper propulsion while minimizing the skating.

On solid ground, the air cushion stops since the peripheral air ejection surface is too large, and the vehicle operates normally while maintaining the entire driveability provided by the traction of the tracks.

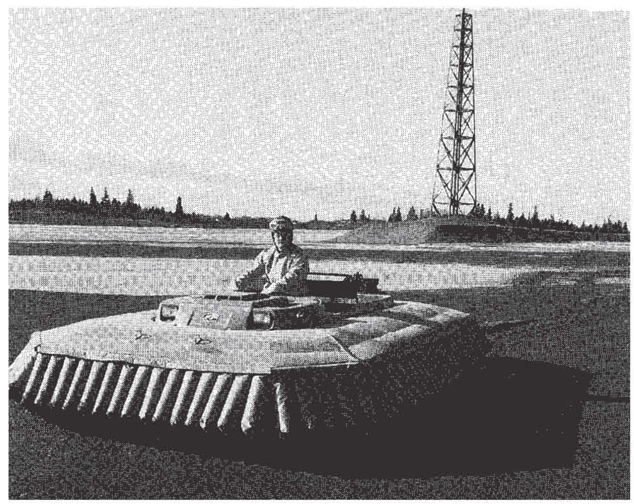
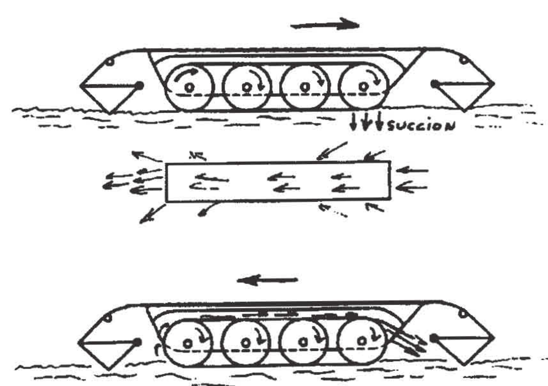


Photo 3
Aero Argo

Movement on Water

Speed is limited by the traction of the tracks in the water. When the tracks turn quickly, they push the water towards the back of the vehicle and the water which was pushed must be replaced; this creates a suction effect on the front of the tracks and the vehicle sinks at the front.

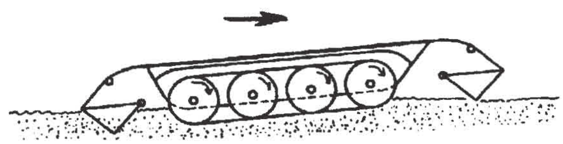
When the tracks turn faster, a reverse thrust is created. The water which remains in contact with the surface of the tracks returns to the front of the vehicle when the tracks come back. It is therefore pushed to the front of the vehicle, in the direction opposite to the movement of the mud. The tangential speed between the water and the immersed part of the tracks is too high to allow the viscosity to act and there is no more pumping under the tracks: the vehicle goes backwards.



Movement in Mud

The tracks sink more at the back than at the front. When the front part of the tracks comes into contact with the mud, the mud has not yet been reshaped. The passage of the track mixes the mud and it becomes less viscous because of its thyxotropy. Rhis explains the sinking caused by a side movement of the mud under the tracks.

This phenomenon emphasizes the skating of the tracks; this liquefies the mud until the back structure sinks into the mud. In this case, it is necessary to reverse the movement of the vehicle a few feet and to slowly begin forward movement again while avoiding skating of the tracks.



This phenomenon occurs only in very viscous mud which is in solidification phase. Otherwise the vehicle behaves as if it were on water.

Technical Data

Cost : $10,000.00 US

BASIC VEHICLE:	ARGO X 8 MAGNUM	
HOVERCRAFT:		
Chassis:	Thin wall metal tubing structure	
	Coated with polyvinyl canvas 0.64 kg/m² (19 oz/yd²)	
	Tensile strength:	1290 N + 1290 N (290 lb. + 290 lb.)
Size:	Length:	4.3 m (170 in)
	Width:	2.7 m (109 in)
	Height:	0.6 m (24 in)
	Cushion area:	11.7 m² (126 ft²)
	Skirt:	104 segmented pads
	Width:	12.5 cm (5 in)
	Height:	0.6 m (24 in)
	Polyvinyl canvas:	0.64 kg/m² (19 oz/yd²)
	Engine:	Brigg Straton 6 kw (8 HP), 3600 RPM
	Propeller:	Crowley 24'' - 39-4ZL-PAG
Performance:	Pressure:	0.77 kPa (16 lb./pi²)
	Flow:	2.36 m³/s (5000 CFM)
	Gliding height:	1.27 cm (0.5 in)

Results

Providing an air cushion system to a tracked vehicle so as to free the chassis from the mud makes it possible to move swiftly in all conditions on the stack site.

However two factors limit the use of this concept: the peripheric air spray causes a mist filled with mud and caustic. It is also difficult to build a vehicle designed to carry heavy weights.

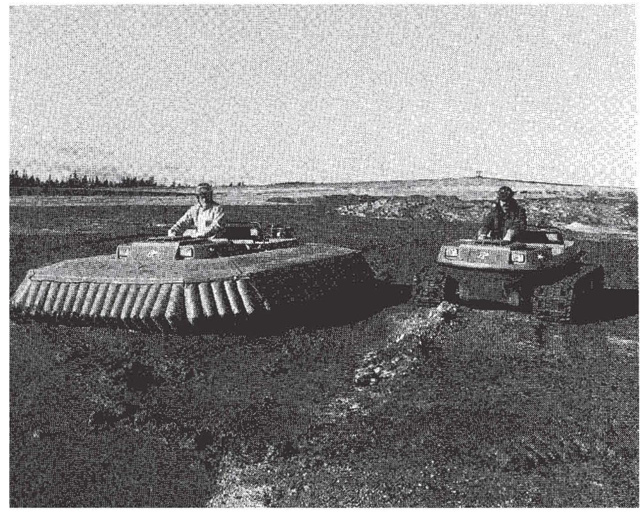


Photo 4
Aero Argo - Argo

Double Argo

Implemented in 1992, the "ARGO" vehicle was modified to allow it to move with a work load in any mud condition.

Modifications

Trailer. The addition of a motorized trailer (photo 5) allowed the creation of a loading and working surface dedicated to the transportation of light material. The first vehicle (the tractor) remains for the transportation of personnel and provides the power unit to the entire vehicle.

Steering. In its original version, the "ARGO" uses a tracks blocking steering. In the mud, the braking of a track forces its opposing track to skid, which brings about a recirculation of the mud thus a traction loss followed by the vehicle getting stuck.

The Double Argo is articulated with hydraulic cylinders located between the tractor and trailor. In changes of direction, the four tracks exert a maximum traction eliminating skidding. Furthermore, it is possible when manoeuvrering in very viscous mud to reduce the suction effects on the shell by exerting a relative movement from left to right between the two vehicles.

Photo 5
Double Argo

Tracks. Trials on traction with added deep cross bars on the tracks did not give positive results. The mud fills the space between the cross bars and the traction is like that of a plain track.

Instead of using the viscosity and shearing characteristics of the mud, a side-blade system was developed, allowing to push the mud, thus creating a pushing force in relation with the mud density.

These blades are attached to the outside of the tracks and do not generate any loss of load-bearing capacity under the tracks associated with the re-circulation of the thyxotropic mud.

Technical Data

Cost: $100,000.00 US from 1992 to 1995

DOUBLE ARGO

Engine:	Suzuki 4 stroke, 30 HP - Gas
Transmission:	Hydrostatic, 4 motors on wheels, 4000 lbs, Pull
Speed:	ground 19 km/h (9MPH)
Number of passengers:	4 persons
Pressure to the ground:	1.6 kPa (0.67 lb/in^2)
Weight:	900 kg (2000 lbs)
Load:	450 kg (1000 lbs)
Length:	9 meters (17 feet)
Width:	2.3 meters (7 feet)
Tires:	16-24 + 12-12 NHS Good Year
Chassis:	Polyethylene
Steering:	Hydraulic - Articulation

Results

This design allows movement over the entire surface of the mud stack in all mud conditions.

The moving speed in very viscous mud is considerably reduced compared to the Aero Argo but site management needs do not require to move on such ground conditions. In the event of a driving error, the driver will not get stuck since he can move backward and find better load-bearing surfaces.

Gypsum Spreading Vehicle

There were serious dust losses from the mud stack in the winter of 1992. This phenomenon can be attributed to the freezing mud at the surface, which stops the hydration of the surface through capillarity from the lower layers. In this condition, before the snow covers the site and in strong winds, the mud at the surface reaches a drying rate of 90%, thus explaining the dust losses.

The solution solving this problem lies in the application of a gypsum layer which becomes hard in the presence of air, thus creating an efficient protective barrier.

The spreading of a gypsum layer of 1.2 cm (½") to 2.5 cm (2") over dozens of hectares required the development of a vehicle able to carry 10 to 15 tons of live load over the dried surfaces of the stack.

It should be noted that the 35 kPa (5 lb/in) load-bearing capacity of the dried mud cannot support the weight of a man.

Trials of Different Heavy Vehicles

Different tracked vehicles of weights varying from 5 to 20 tons and exerting a load to the ground of 35 kPa (5 psi) were evaluated. Even though this load-bearing capacity made it possible to operate with traditional tracked vehicles, these vehicles do get stuck (photo 6). The thin, hard crust rests on the lower viscous mud layers much like ice over water. When a large weight is concentrated in one place, the crust breaks, even under pressure lower than 35 kPa (5 lb/in). An additional consideration must be paid to the shearing forces in the periphery of the cushion area.

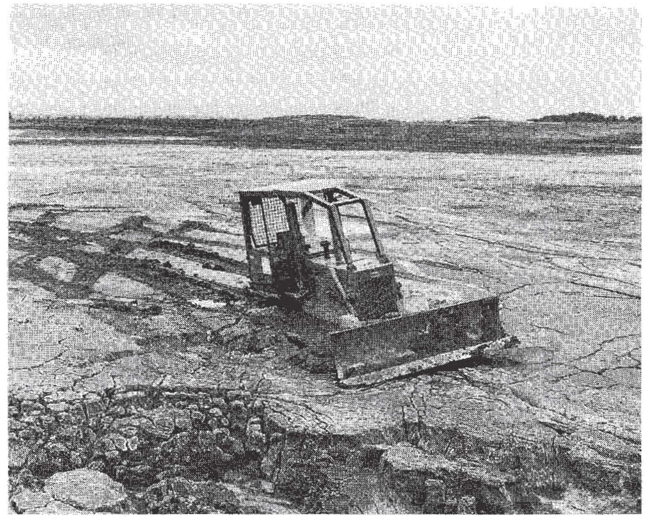


Photo 6
Stuck Heavy Low Ground Vehicle

Example:

Following is a comparison of two cushion areas with respective diameters of 2 meters and 4 meters and a ground pressure of 35 kPa (5 lb/in^2):

Diameter	2 m (6.56 ft)	4 m (13.13 ft)
Cushion Area	3.14 m^2 (33.8 ft^2)	12.6 m^2 (135 ft^2)
Weight to the ground with a pressure of 35 kPa (5 lb/in^2)	108 kN (24 300 lbs.)	434 kN (97 000 lbs.)
Perimeter	6.2 m (20.6 ft)	12.6 m (41.2 ft)

The carried weight increases with the diameter squared whereas the perimeter is proportional to that dimension.

In the case of heavy vehicles, the lower layers do not give enough support and the crust breaks, thus causing the vehicles to get stuck.

Balloon Tires

The use of large size soft tires (photo 7) solved the problem. A tire with a diameter of 2 meters by 2 meters width built in kevlar supports a 2.5 ton load at a pressure of 14 kPa (2 psi). This tire is equipped with a 4 ton capacity waterline, making the vehicle amphibian without any rigid structure.

The high flexibility of the thin wall of this tire (1.2 cm) makes it possible to follow the outlines of the ground and allows for an efficient distribution of the shearing forces over a large surface.

The tires used offer a large load capacity, low pressure to the ground and little peripheric shearing force. On the other hand, the smooth surface of the tire offers no traction in non-consolidated mud. In this condition, the tires float on the mud and skid.

Photo 7
Gypsum Spreading Vehicle

Spreading System

In order to cover the site with a uniform layer of gypsum, the vehicle is equipped with a loading box having a capacity of 13.8 m^3, which pours back into a side spreading system with a capacity of 6.5 m^3 (photo 8). A chain conveyor located at the bottom of the box and spreader, spreads a 1.3 cm thick uniform layer of gypsum at a speed of 30 tons/hr.

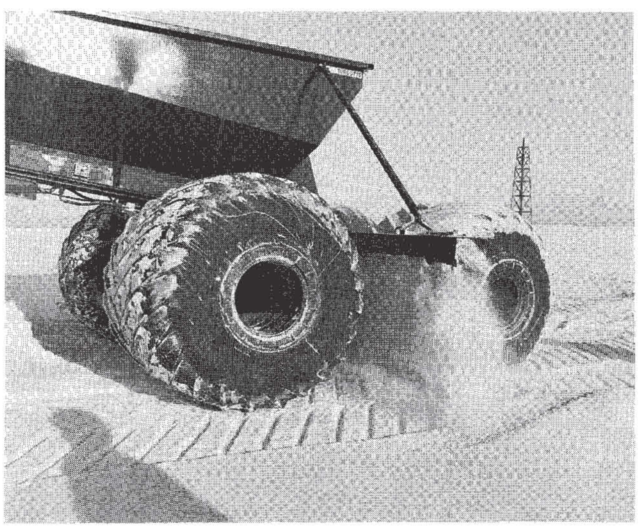


Photo 8
Spreading Gypsum

To cover one hectare (100,000 m^2), the vehicle must go back and forth 55 times.

Technical Data

Cost:	300 K 6 months to develop
Engine:	Carterpillar - 250 HP - Diesel
Transmission:	Hydrostatic - 4 Hydraulic Motors linked with 4 differentials
Weight:	15 tons
Load:	10 tons
Length:	14 meters (42 ft)
Width:	5.5 meters (16 ft)
Tires:	8 x (68" + 68" + 24' - 4 PLI)
Pressure to the ground:	20 kPa (3 lb/in^2)
Buoyancy:	32 tons
Spreading box:	13.8 m^3 (10 yd^3)
Spreader:	6.5 m (20 ft wide) 30 tons/hr capacity
Speed:	10 km/hr

Results

The gypsum spreading vehicle is the only efficient tool to control dust losses from the mud stack.

The spreading operation on the site is carried out in reverse motion. When the back tires of the vehicle break the bearing layer (crust), then the operator begins spreading in forward motion. This technique seems very effective at preventing the vehicle from becoming stuck.

Conclusion

At first glance, it seems that the stackable red mud does not possess any characteristic in favor of a moving vehicle.

Its thyxotropic character makes any kind of traction impossible. The viscosity generates an important resistance to the movement of any immerged object, and during drying the surface crust does not bear the shearing forces.

The development program undertaken in 1991 permitted a systematic analysis of the behavior of the mud and the obtained results transformed positively all its disadvantages. The thyxotropy makes it impossible to create a traction force but the viscosity allows for an efficient propulsion with a track equipped with side blades.

The surface hardened layer is very elastic and soft balloon tires can deform it without shearing forces in order to generate an important load-bearing capacity. Balloon tires generate their own buoyancy thus eliminating resistance to the forward movement caused by the viscosity of a rigid and fixed floating system.

Two vehicles from this program offer solutions to mobility problems encountered on the mud stack. The last phase of this development program is to finalize rigid tracks equipped with inflatable hemispheric balloons. This project should combine the advantages of the traction provided by the rigid tracks with the load-bearing capacity of the balloon tires.