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Slurry Transportation and Its Effect on Dredge Pipe in a Dredger

[1]Pushkal Srivastava, [2]Karanbir Singh Sidhu, [3]Shahbaz Singh

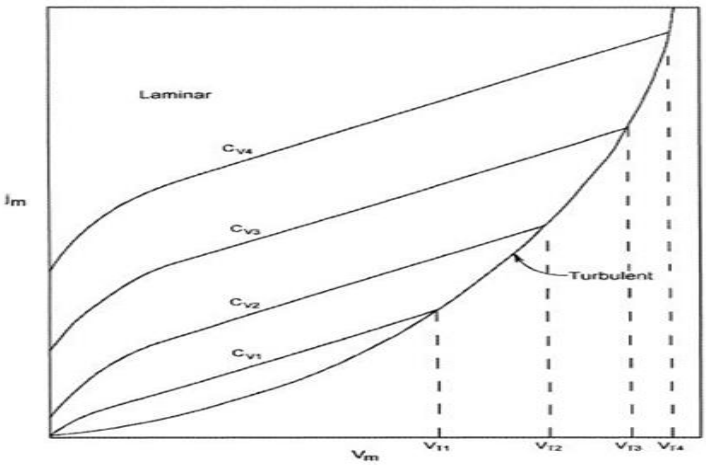
[1, 2] M.Tech Students in Dredging and Harbour Engineering, IMU, Visakhapatnam
[3]Lecturer, GNDPC, Ludhiana, Punjab

Abstract: **There is a great deal of misinformation in the industry on pumping high density, viscous slurries. These misconceptions become "accepted truths" as time goes on and at best hinder and at worst stop, implementation of appropriate technology. Unfortunately, the root of these misconceptions is often due to experiences gained on poorly understood, designed or implemented systems. Advancement in a technology can only be realized by formulation of new methods of calculation. The objective of this project is to address some issues by tracing historic development of pumping and how the efficiency can be increased. It is accepted that many of the fundamental problems cannot be resolved and continued improvements in slurry transport will mean that new challenges will arise. However, there is a better understanding of how to increase the efficiency by varying pipe diameters.**

Keywords: **slurry transport, industry, varying pipe diameters.**

1. INTRODUCTION

Vast tonnages are pumped every year in the form of solid-liquid mixtures, known as slurries. The application which involves the largest quantities is the dredging industry, continually maintaining navigation in harbours and rivers, altering coastlines and winning material for landfill and construction purposes. As a single dredge may be required to maintain a through put of 7000 tonnes of slurry per hour or more, thus very large centrifugal pumps are used. For slurries of very fine particles — say with hindered settling velocity less than about 1.5 x 10"^ m/s — then the tendency for the particles to settle out from the liquid can be neglected. As a result, the slurry can be treated for most purposes as a single-phase fluid. The particles move at the local fluid velocity. Therefore the delivered and *in situ* concentrations are identical and, provided that the line is not left full of stagnant slurry for an extended period, a stationary bed of solids does not form. Set against these simplifications is the fact that the slurry usually shows non-Newtonian behaviour. As a result of these general properties, the friction gradient for a non-settling slurry varies with mixture velocity and solids concentration. The friction gradient, jm, is given in terms of the head loss of mixture. The rising curve to the right of the figure represents turbulent flow. If the friction factor is constant, the turbulent curve is a single line with jm proportional to v_m, as shown on the figure. If the friction factor varies with volumetric solids concentration Cy, turbulent flow will be represented by a bundle of curves rather than a single curve.



Effect of Concentration on Friction Gradient for Homogenous slurries.

The behaviour in laminar flow depends strongly on solids concentration, *via* the rheological characteristics of the slurry. Figure 3.1 shows laminar flow lines for a series of concentrations, increasing from Cvi to Cv4. The first of these, Cvi, represents a relatively low solids concentration. This curve for laminar flow passes through or close to the origin, corresponding to zero or negligible yield stress. The friction gradient typically increases less than proportionately to Vm. At mixture velocity VTI the laminar flow characteristic intersects the characteristic for turbulent flow. As a first approximation this x intercept can be taken as the transition between laminar and turbulent flow.

2. METHODOLOGY

Soil properties are established by sampling of marine soils and forwarding the sample to laboratory for testing. Generally, in shallow waters the techniques of drilling and sampling used on land can be adapted, utilizing a jackup barge or a fixed platform. In the deep ocean, because of the great water depth, the sampling of soil sediments often involves more complicated equipment and techniques than sampling on land or near shore. In deeper waters, sampling must be done from a floating vessel. Gravity corers and vibracorers are usually used to obtain samples in the upper 10 to 20 feet. Below this soil depth, drilling rigs and wire line sampling techniques are normally used. The performance of these sampling techniques in the deep ocean is limited by the handling capability of the supporting vessel and the weather conditions. Once the soil has been identified whether sand or clay, its concentration as slurry on transportation pipe is estimated. In this paper, no attempt is made to provide a general formula for the calculation of the pipeline resistance for straight pipes, only calculations are made on basis of most commonly used formulae.

3. CONCENTRATION IN PIPELINE

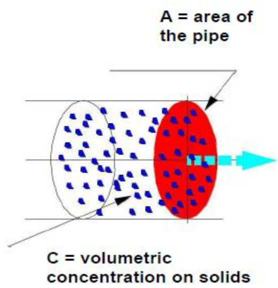
The mixture flow Q will be defined as the amount of mixture passing through the cross section of the pipe per unit of time. In a closed system the flow is equal for all the cross sections and the average mixture velocity for a certain cross-section follows from**:**

$$v_m = \frac{Q_m}{\frac{\pi}{4} \cdot D^2} \quad m/s$$

Where Q_m =Mixture flow in m^3/s

D = Diameter of pipe in m

V_m = average velocity in m/s



When the pipe line system is made from parts with different diameter the flow in all the parts will be the same and thus the velocity differs. This must be taken in account when the mixture is transported with very low speeds. Locally it will be possible that the mixture velocity becomes too low, resulting in a depot in the pipeline. As a result of the depot in the pipeline, the cross section available for the passage of the mixture will be reduced and the local mixture velocity will be increased. For the calculation of the mean velocity the total cross-section of the pipe is still being used.

For the mixture:

$Mass_{mixture} = Mass_{grains} + Mass_{water}$ or $\rho_m . V_m = \rho_g . V_g + (V_m - V_g) . P_w$

Dividing by V_m we get

$\rho_m = \rho_g . C_v + (1 - C_v) . \rho_w$ as $C_V = V_g / V_m$

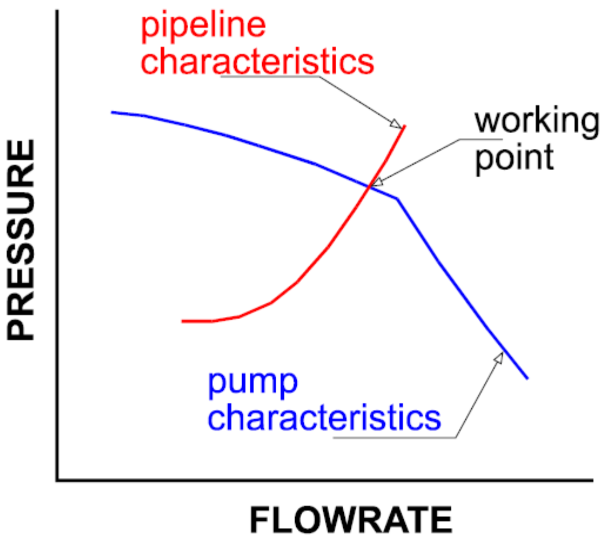
C_v is volumetric concentration of grains

V_g is volume of grains

V_m is Volume of total mixture

A property of the soil, which is important for dredging, is the density of the components in the mixture. The density is the mass of the solid divided by the volume of the solid. There is a wide range of applications when solids being conveyed have a density of the grain around 2650 kg/m^3, a typical value for sand and gravel. Values of densities for many materials, such as minerals, ores, rocks, etc. may be found in various handbooks. The liquid most commonly used is **fresh water with a density of about 1000 kg/m^3**, but in marine dredging operations, the carrier fluid is **sea water, hence the density is 1025 kg/m^3**. The volumetric concentration is based on the density of the grain and therefore the production calculated with this concentration is the amount of transported solids. This production is for aggregate mining very important, for capital and maintenance dredging the amount of m3 soil dredged from a harbour or brought to a deposit will be important. Soil consists of a combination of grains and water (sometimes also gas). The presence of water, with a lower density, in the voids between the grains results in a reduction of the density of the soil. The combined density is called the density in situ of the soil ρ_s.

4. RESISTANCE IN PIPELINE



The working point or manometric head of a dredge pump is determined by the intersection, in the Q-H diagram, of the pump characteristics and the pipeline characteristics. The pipeline characteristics is the sum of all the resistance's in the suction and discharge pipeline of a hydraulic transport system and includes also the effects of acceleration and the pressure loss due to changes in pipe elevation. The most important system parameter is how pressure head varies with slurry flow rate, depicted by the system curve. This relationship is used to match pump and system characteristics, and to predict the likely maximum pressure within the systems so that suitable pipe materials and wall thickness can be specified. The head of the dredge pump must be enough to overcome all the resistances, including the acceleration and the geodetic head, within the normal working range of a dredge pump. Total pressure losses need to be estimated before a pump type can be selected and sized, and its power requirements assessed. Before the resistance curve can be determined, a schematic diagram of the pipe line lay-out is required. This includes pipe section lengths and diameters, bends, hoses, Y-pieces, suction and discharge arrangements and changes in elevation. The liquid most commonly used for the transportation is water although liquors, brines and hydrocarbons have been used. The solids are usually products of the mineral industry although agricultural and food products are also pipelines in slurry form. The mineral solids may be raw ores, beneficiated ores and tailings.

Slurry friction losses through pipes and fittings can be estimated using a wide range of empirical, semi-empirical or analytical equations. In literature an enormously number of formulas is given, most of them only valid for a small range of applications and extrapolation can led to a disastrously result.

5. CALCULATIONS AND RESULTS

For Sand:

for sand

wt of solids in slurry in tons/hr	Sp gr of solids S	Cw (%)	Wt of Vol of water eql to solids volume	wt of water in slurry of Cw 30%
2100	2.65	30	792.453	4900
2100	2.65	30	792.453	4900
2100	2.65	30	792.453	4900
2100	2.65	30	792.453	4900
2100	2.65	30	792.453	4900
2100	2.65	30	792.453	4900
2100	2.65	30	792.453	4900
2100	2.65	30	792.453	4900
2100	2.65	30	792.453	4900

Total weight of slurry mixture	Total weight of equal volume of water	Quantity of slurry (gpm)	Quantity of slurry (cu m/hr)
7000	5692.45	22751.6	5164.62
7000	5692.45	22751.6	5164.62
7000	5692.45	22751.6	5164.62
7000	5692.45	22751.6	5164.62
7000	5692.45	22751.6	5164.62
7000	5692.45	22751.6	5164.62
7000	5692.45	22751.6	5164.62
7000	5692.45	22751.6	5164.62
7000	5692.45	22751.6	5164.62

dia of pipe in inches	ft	mm	Slurry mixture velocity V (ft/s)	Slurry mixture velocity V (m/s)	Vl ft/s
30	2.499	762	10.3267	3.14758	9.34946
29	2.4157	736.6	11.0512	3.3684	9.19231
28	2.3324	711.2	11.8546	3.61329	9.03244
27	2.2491	685.8	12.749	3.8859	8.86968
26	2.1658	660.4	13.7486	4.19056	8.70387
25	2.0825	635	14.8705	4.53251	8.53485
24	1.9992	609.6	16.1355	4.91809	8.36241
23	1.9159	584.2	17.5691	5.35505	8.18634
22	1.8326	558.8	19.2025	5.85294	8.0064

Type of Solids	Size of Solids (Mesh No)	Flow Velocity	
		m/s	ft/s
Fine	over 200	1 – 1.5	3 – 5
Sand	200 – 20	1.5 – 2	5 – 7
Coarse	20 – 4	2 – 3.25	7 – 11
Sludge		3.25 – 4.25	11 – 14

wt of solids in slurry in tons/hr	Sp gr of solids S	Cw (%)	Wt of Vol of water eql to solids volume	wt of water in slurry of Cw 30%
1900	2.65	30	716.981	4433.33
1900	2.65	30	716.981	4433.33
1900	2.65	30	716.981	4433.33
1900	2.65	30	716.981	4433.33
1900	2.65	30	716.981	4433.33
1900	2.65	30	716.981	4433.33
1900	2.65	30	716.981	4433.33
1900	2.65	30	716.981	4433.33
1900	2.65	30	716.981	4433.33

Total weight of slurry mixture	Total weight of equal volume of water	Quantity of slurry (gpm)	Quantity of slurry (cu m/hr)
6333.33	5150.31	20584.8	4672.75
6333.33	5150.31	20584.8	4672.75
6333.33	5150.31	20584.8	4672.75
6333.33	5150.31	20584.8	4672.75
6333.33	5150.31	20584.8	4672.75
6333.33	5150.31	20584.8	4672.75
6333.33	5150.31	20584.8	4672.75
6333.33	5150.31	20584.8	4672.75
6333.33	5150.31	20584.8	4672.75

dia of pipe in inch	ft	mm	ture velocity V (ft/s)	Slurry mixture velocity V (m/s)	Vl ft/s
30	2.499	762	9.34321	2.84781	9.34946
29	2.4157	736.6	9.99868	3.0476	9.19231
28	2.3324	711.2	10.7256	3.26917	9.03244
27	2.2491	685.8	11.5348	3.51581	8.86968
26	2.1658	660.4	12.4392	3.79146	8.70387
25	2.0825	635	13.4542	4.10085	8.53485
24	1.9992	609.6	14.5988	4.4497	8.36241
23	1.9159	584.2	15.8958	4.84504	8.18634
22	1.8326	558.8	17.3737	5.29551	8.0064

wt of solids in slurry in tons/hr	Sp gr of solids S	Cw (%)	Wt of Vol of water eql to solids volume	wt of water in slurry of Cw 30%
1700	2.65	30	641.509	3966.67
1700	2.65	30	641.509	3966.67
1700	2.65	30	641.509	3966.67
1700	2.65	30	641.509	3966.67
1700	2.65	30	641.509	3966.67
1700	2.65	30	641.509	3966.67
1700	2.65	30	641.509	3966.67
1700	2.65	30	641.509	3966.67
1700	2.65	30	641.509	3966.67

Total weight of slurry mixture	Total weight of equal volume of water	Quantity of slurry (gpm)	Quantity of slurry (cu m/hr)	cu m/s
5666.67	4608.18	18418	4180.88	1.16136
5666.67	4608.18	18418	4180.88	1.16136
5666.67	4608.18	18418	4180.88	1.16136
5666.67	4608.18	18418	4180.88	1.16136
5666.67	4608.18	18418	4180.88	1.16136
5666.67	4608.18	18418	4180.88	1.16136
5666.67	4608.18	18418	4180.88	1.16136
5666.67	4608.18	18418	4180.88	1.16136
5666.67	4608.18	18418	4180.88	1.16136

dia of pipe in inch	ft	mm	m	Slurry mixture velocity V (ft/s)	Slurry mixture velocity V (m/s)	Vl ft/s
30	2.499	762	0.762	8.35971	2.54804	9.34946
29	2.4157	736.6	0.7366	8.94618	2.7268	9.19231
28	2.3324	711.2	0.7112	9.59661	2.92505	9.03244
27	2.2491	685.8	0.6858	10.3206	3.14573	8.86968
26	2.1658	660.4	0.6604	11.1298	3.39236	8.70387
25	2.0825	635	0.635	12.038	3.66918	8.53485
24	1.9992	609.6	0.6096	13.062	3.98131	8.36241
23	1.9159	584.2	0.5842	14.2226	4.33504	8.18634

wt of solids in slurry in tons/hr	Sp gr of solids S	Cw (%)	Wt of Vol of water eql to solids volume	wt of water in slurry of Cw 30%
700	2.65	30	264.151	1633.33
700	2.65	30	264.151	1633.33
700	2.65	30	264.151	1633.33
700	2.65	30	264.151	1633.33
700	2.65	30	264.151	1633.33
700	2.65	30	264.151	1633.33
700	2.65	30	264.151	1633.33
700	2.65	30	264.151	1633.33
700	2.65	30	264.151	1633.33

Total weight of slurry mixture	Total weight of equal volume of water	Quantity of slurry (gpm)	Quantity of slurry (cu m/hr)	inlet pipe dia	suction pipe velocity (must be<disch vel. 2m/s)
2333.33	1897.48	7583.87	1721.54	0.765	2.5282
2333.33	1897.48	7583.87	1721.54	0.77	2.49547
2333.33	1897.48	7583.87	1721.54	0.78	2.4319
2333.33	1897.48	7583.87	1721.54	0.79	2.37072
2333.33	1897.48	7583.87	1721.54	0.87	1.95477
2333.33	1897.48	7583.87	1721.54	0.81	2.25509
2333.33	1897.48	7583.87	1721.54	0.83	2.14772
2333.33	1897.48	7583.87	1721.54	0.85	2.04784
2333.33	1897.48	7583.87	1721.54	0.86	2.0005

dia of pipe in inch	ft	mm	ture velocity V (ft/s)	Slurry mixture velocity V (m/s)	Vl ft/s
17	1.4161	431.8	10.7198	3.26738	7.03802
20	1.666	508	7.74503	2.36068	7.6338
23	1.9159	584.2	5.85635	1.78502	8.18634
25	2.0825	635	4.95682	1.51084	8.53485

Calculating Pipe Velocity

Pipe velocity (m/s) = 1.274 q/d^2

where q = volume flow (m^3/s)
and d = pipe inside diameter (m)

http://www.michael-smith-engineers.co.uk/resources/useful-info/suction-pipeline-design

Re	f
2712824	0.032

$$i_w = f \cdot \frac{V^2}{2gD}$$

length of pipe in mt	Hf in mt	loss at pipe dischrg in meters	iw in mt	loss at pipe suction in meters	suction head in m
300	4.17323	0.252412845	0.00031	0.413776517	3

$$f = \frac{1.325}{\left[\log_e\left(\frac{k}{3.7D} + \frac{5.74}{Re^{0.9}}\right)\right]^2}$$

Total head (H): It is the sum of the static head Hs, friction head (hf) and the velocity head in the delivery pipe (Vd 2/2g). Where, Vd=velocity in the delivery pipe

$$\therefore H_a = \left(h_s + h_d + h_f + \frac{Vd^2}{2g}\right) \text{---(1)}$$

Manometric head(Hm): It is the total head developed by the pump. This head is slightly less than the head generated by the impeller due to some losses in the pump

$$\therefore H_m = H + \frac{Vs^2}{2g} - \frac{Vd^2}{2g}$$

discharge head in m	α	im
7	0.5	0.00037

TDH in m	manometric head	kPa	ext impeller dia D2	internal dia D1	N(rpm)	in vane angle ɵ		outlet vane angle ϕ
14.9186	14.79150742		0.8	0.4	600	20		30
							2.23716	

in tan vel u1	in tan vel u2	Vf1	Vf2	
12.56	25.12	3.42	3.42	Vf2=Vf1=tanɵ*u1
		Vw2		
		12.87		Vw2=u2-(tanϕ/Vf2)

WD by impeller	eff %	power in kW
32.95559633	*44.8831*	1351.654831

For Clay:

wt of solids in slurry in tons/hr	Sp gr of solids S	Cw (%)	Wt of Vol of water eql to solids volume	wt of water in slurry of Cw 30%
1700	1.8	30	944.444	3966.67
1700	1.8	30	944.444	3966.67
1700	1.8	30	944.444	3966.67
1700	1.8	30	944.444	3966.67
1700	1.8	30	944.444	3966.67
1700	1.8	30	944.444	3966.67
1700	1.8	30	944.444	3966.67
1700	1.8	30	944.444	3966.67
1700	1.8	30	944.444	3966.67

for clay

Total weight of slurry mixture	Total weight of equal volume of water	Quantity of slurry (gpm)	Quantity of slurry (cu m/hr)	cu m/s
5666.67	4911.11	19628.7	4455.72	1.2377
5666.67	4911.11	19628.7	4455.72	1.2377
5666.67	4911.11	19628.7	4455.72	1.2377
5666.67	4911.11	19628.7	4455.72	1.2377
5666.67	4911.11	19628.7	4455.72	1.2377
5666.67	4911.11	19628.7	4455.72	1.2377
5666.67	4911.11	19628.7	4455.72	1.2377
5666.67	4911.11	19628.7	4455.72	1.2377
5666.67	4911.11	19628.7	4455.72	1.2377

dia of pipe in inch	ft	mm	m	Slurry mixture velocity V (ft/s)	Slurry mixture velocity V (m/s)	Vl ft/s	inlet pipe dia	suction pipe velocity (must be<disch vel.)
30	2.499	762	0.762	8.90927	2.71554	9.34946	0.72	3.04173
29	2.4157	736.6	0.7366	9.53429	2.90605	9.19231	0.77	2.65952
28	2.3324	711.2	0.7112	10.2275	3.11733	9.03244	0.78	2.59177
27	2.2491	685.8	0.6858	10.9991	3.35252	8.86968	0.79	2.52657
26	2.1658	660.4	0.6604	11.8615	3.61537	8.70387	0.87	2.08328
25	2.0825	635	0.635	12.8293	3.91038	8.53485	0.81	2.40334
24	1.9992	609.6	0.6096	13.9207	4.24304	8.36241	0.83	2.28891
23	1.9159	584.2	0.5842	15.1575	4.62002	8.18634	0.85	2.18247
22	1.8326	558.8	0.5588	16.5668	5.04957	8.0064	0.86	2.13201

Re	f
2068423	0.032

$$i_w = f \cdot \frac{V^2}{2gD}$$

Calculating Pipe Velocity

Pipe velocity (m/s) = 1.274 q/d²

where q = volume flow (m³/s)

and d= pipe inside diameter (m)

length of pipe in mt	Hf in mt	loss at pipe dischrg in meters	iw in mt	loss at pipe suction in meters	suction head in m
300	4.73995	0.495804837	0.02082	0.472046108	3

discharge head in m	α	im
7	0.5	0.0226

TDH in m	manometric head	ext impeller dia D2	internal dia D1	N(rpm)	in vane angle ɵ	outlet vane angle ϕ
15.6317	15.60789506	0.8	0.4	500	20	30

Vw2=u2-(tanϕ/Vf2)

in tang vel. u1	in tang. vel u2	Vf1	Vf2	
10.46666667	20.93333333	3.42	3.42	Vf2=Vf1=tanɵ*u1
		Vw2		
		12.87		

WD by impeller	eff %	power in kW
27.46299694	*56.8325*	1200.425598

6. CONCLUSIONS

For sand:

1) Total payload was 16000 tons. The aim was to calculate the slurry flowrate through the diameter of pipe(keeping diameter constant) and calculating power and efficiency for the same.

2) With various calculations it was concluded that for a flow rate of 4180.879 cum /hr, the pipe diameter required is 30inch (762mm)and the required velocity is 2.54m/s(as specified for coarse sand 2-3.25m/s).

3) The frictional losses for 300m length of pipe is 4.17m.The suction head and discharge head was 3m and 7 m respectively.

4) According to thumb rule of centrifugal pumps,the suction velocity must be kept lower than the delivered velocity that is less than or equal to 2m/s in this case. Therefore, the suction velocity from the calculation is 2m/s with corresponding inlet pipe diameter of 860mm.

5) After considering the loss at pipe discharge (0.25m) and loss at pipe suction(0.4m) the manometric head was 14.8m.

6) Hence the efficiency and power of the required centrifugal pump with the above parameters for pumping sand is 44.88% and 1351.51kW.

For Clay:

1) Total payload was 16000 tons. The aim was to calculate the slurry flowrate through the diameter of pipe (keeping diameter constant) and calculating power and efficiency for the same.

2) With various calculations it was concluded that for a flow rate of 1834.71 cum /hr, the pipe diameter required is 30inch(762mm) and the required velocity is 2.712m/s.

3) The frictional losses for 300m length of pipe is 0.8m. The suction head and discharge head was 3m and 7 m respectively.

4) Keeping the suction diameter of pipe same as that for sand (860mm).The required suction velocity was 0.75m/s

5) After considering the loss at pipe discharge (0.06m) and loss at pipe suction (0.03m) the manometric head was 10.8m.

6) Hence the efficiency and power of the required centrifugal pump with the above parameters for pumping sand is 56.5% and 1200.42kW

From the calculation by varying the payloads the delivery pipe diameter can be decided and the best of four can be selected and the same should be kept constant. By this constant value the pump flowrate can be calculated which can be varied by varying the rpm of pump when the pump impeller is kept constant.

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