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Enhancing the Lifting Capacity of Drilling Fluids in Vertical Oil Wells

Amel habeeb Assi
Petroleum Engineering Dept. / University of Baghdad

Abstract

Of the many functions that are performed by the drilling fluid, the most important is to transport cuttings from the bit up the annulus to the surface. Various drilling fluid have been widely used in the oil industry to improve lifting capacity. In this study, three mud type have been used which they are, oil base mud, X-anthan polymer and a mixture of CMC and bentonite ,by using Carrying Capacity Index calculation (CCI) , the Xanthan gave good values of CCI than other studied drilling fluid. By using Sifferman chart and field data from well in south of Iraq and API equation to find cutting concentration in the annulus, The results showed that the used of thick mud increase the lifting capacity and decrease volumetric drill cuttings in the annulus but the using thin mud lead to decrease lifting capacity and increase volumetric drill cuttings in the annulus .The results show that the mud viscosity and flow rate have important role in hole cleaning. Also, the effect of annulus velocity and flow pattern on cutting transport ratio is studied by using field data. The effect of cutting size and OD of drill pipe is also studied. Cutting size is one of the parameters that influence the hole cleaning; large size cutting makes the hole cleaning more difficult. The reducing of annular size of hole by increasing the OD of drill pipe lead to increasing the annular velocity.

Key words: lifting capacity, cutting transport,drilling fluid, viscosity.

Introduction

This work contain studying of many factors that have been affect on lifting capacity of drilling fluid ,like the effect of mud type and the value of flow rate on lifting capacity, also the effect of flow patterns on the lifting capacity. Efficient transportation of cuttings is a vital factor for a good drilling program Cutting transport in annulus is a complex problem that is affected by numerous parameters.

The ability of a circulating drilling fluid to transport rock fragments out of a well bore. A solid particle in the hole is acted on by four factors: gravity, viscos drag, impact and bouncy, the problems associated with inefficient hole cleaning include: decreased bit life and slow penetration resulting from regarding of drill cuttings and increasing in annular density and, in turn, annular hydrostatic pressure of mud .the increased hydrostatic pressure of mud may cause the fracture of an exposed weak formation resulting in lost circulation Darley[1]. Carrying capacity is an essential function of a drilling fluid, carrying capacity is determined principally by the annular velocity, hole angle and flow profile of the drilling fluid. For the effective drilling cuttings generated by the drill bit must be removed immediately. The drilling mud carries the drill cuttings up the hole and to the surface, to be separated from the mud.

The carrying of lifting capacity of mud is depend on several parameters including fluid density ,viscosity, type of flow ,annulus size, annular speed ,particle shape and particle diameter. Other factors such as pipe rotation, pipe eccentricity, also have some influence on the carrying capacity of the mud. API13A[2].

Cutting Transport

One of the primary functions of a drilling fluid is to bring the drilled cuttings to the surface. Inadequate hole cleaning can lead to a number of problems, including hole fill, packing off, stuck pipe, and excessive hydrostatic pressure. The ability of a drilling fluid to lift cuttings is affected by many factors, and there is no universally accepted theory which can account for all observed phenomena.

Some of the parameters which affect cuttings transport are the fluids density and viscosity, annular size and eccentricity, annular velocity and flow regime, pipe rotation, cuttings Density, and the size and shape of the cuttings. If the cuttings are of irregular shape (and most are) they are subjected to a torque caused by the shearing of the mud Walker [3]. If the drill pipe is rotating, a centrifugal effect causes the cuttings to move towards the outer wall of the annulus. The process is further complicated because the viscosity of non-Newtonian fluids varies according to the shear rate, and therefore the velocity of the cutting changes with radial position. Finally, transport rates are strongly dependent on cutting size and shape Young [4].

Cutting Slip Velocity

A rock particle falling through mud tends to settle out at constant velocity (zero acceleration) described as a slip velocity.

A cutting, traveling up the annulus, experiences a positive upward force due to the drilling fluid velocity, density and viscosity, and a negative downward force due to gravity. The rate at which a cutting falls is known as its “slip velocity”. Several studies have enabled the following generalizations to be made:

1. The most important factors controlling adequate cuttings transport are annular velocity and rheological properties.
2. Annular velocities of 50 ft/min provide adequate cuttings transport in typical muds.
3. Cuttings transport efficiency increases as fluid velocity increases.
4. The slippage of cuttings as they are transported induces shear thinning of the mud around the cutting reducing the expected transport efficiency.
5. Cutting size and mud density have a moderate influence on cuttings transport.

Those who have observed a solids tracer emerging over the shale shaker will realize the large spread of “cuttings” that occurs. Therefore, any calculated estimation of slip velocity will only be an approximation. The reason for this “spread” of solids is the particles ability to be carried by the drilling fluid. It is a function of its position in the mud stream and the size of the particle O’Brien [5]. Cuttings will travel up the annulus more efficiently if they travel flat and horizontally. If the cutting turns on its edge, it will slip more easily. Smaller cuttings are more prone to do this.

Rotation of the drill pipe will result in a helical motion of the fluid, which will aid transport for those cuttings nearest the pipe API RP 13I,[6]. The rheological properties of the drilling fluid will affect cuttings transport, in as much as they affect the flow profile.

Lowering the “n” value or an increase in the YP/PV ratio will generally flatten the flow profile and increase carrying capacity Barnes [7].

Effect of Major Drilling Parameters on Cuttings Transport

Summary of the influence of major drilling parameters on cuttings transport in wells are presented as follows:

1- Rotation speed: as pipe rotate, it reduces eccentricity and also alters the velocity distribution. Significant positive effect, in small annulus the effect of rotation is more dominate than a large annulus. Rotation is also an effective element in removing small cuttings; a rotate pipe drags the cutting from low side of annuals to the high side. As shown in Fig. (1).

2- Mud type –three type of mud has been studied to show the effect of mud type on cutting transport. Those three mud type are fresh water bentonite, gel bentonite mud, and polymer mud. Those three mud type are really used in the field to drill three wells in south of Iraq, hole Size: 12.25″ hole, Depth: from 650m to 2022 m. The laboratory measurements for each mud type are given in table (1), table (2), and table (3), and as shown in fig.2.It's clear that the polymer mud type is the best mud because is give good lifting capacity compared with the other studied mud type. Also the gel bentonite mud type gave good lifting capacity.

3- Mud weight –the high mud density can transport the cutting through the annulus faster than the low mud density. For the effect of fluid density on cutting transport, three fluid densities were considered. These are 9.32, 11.66 and 12.91ppg. At the high annular velocity the curve of high mud density and low mud density are close to each other but at the low annular velocities the high mud density performs better than low mud density. In other words low mud density coupled with high annular velocity can give good hole cleaning and as shown in Fig. (3)

4- Mud rheology-moderate positive or negative effect depending on the cuttings size, pipe rotation, hole inclination, and annular eccentricity and as shown in Fig.(4), Increasing the plastic viscosity is not a desirable means of Increasing the hole-cleaning ability of a mud. In fact, the increase in pressure drop down the drill string, caused by an increase in PV, would reduce the available flow rate and tend to offset any increase in lifting ability. In general, high plastic viscosity is never desirable and should be maintained as low as practical.

5- Cutting size- is one of the parameters that influences the hole cleaning, for this analysis the small, medium and large sized cuttings were considered for the analysis. Hopkin [8].

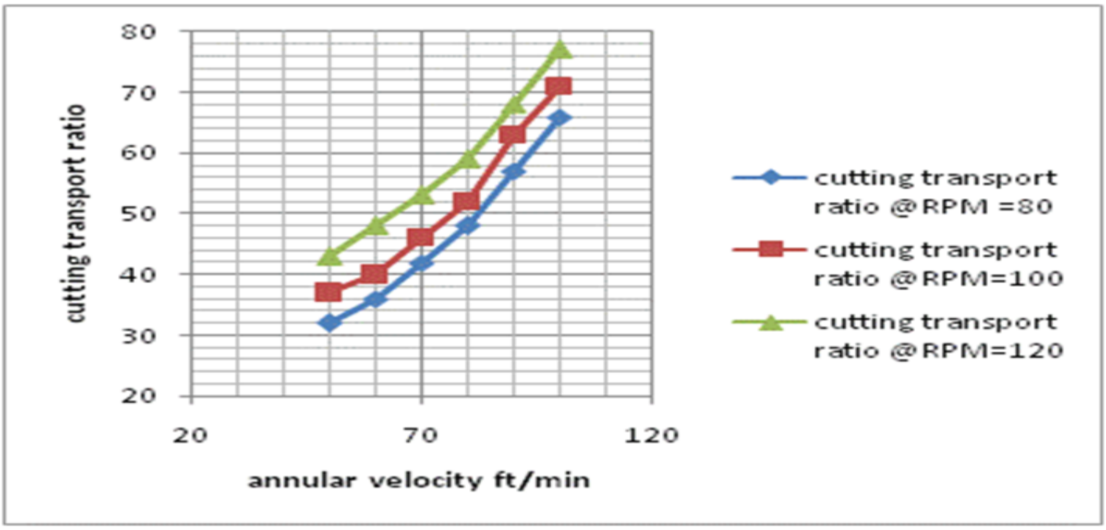

Fig. 1, The effect of RPM values on cutting transport ratio

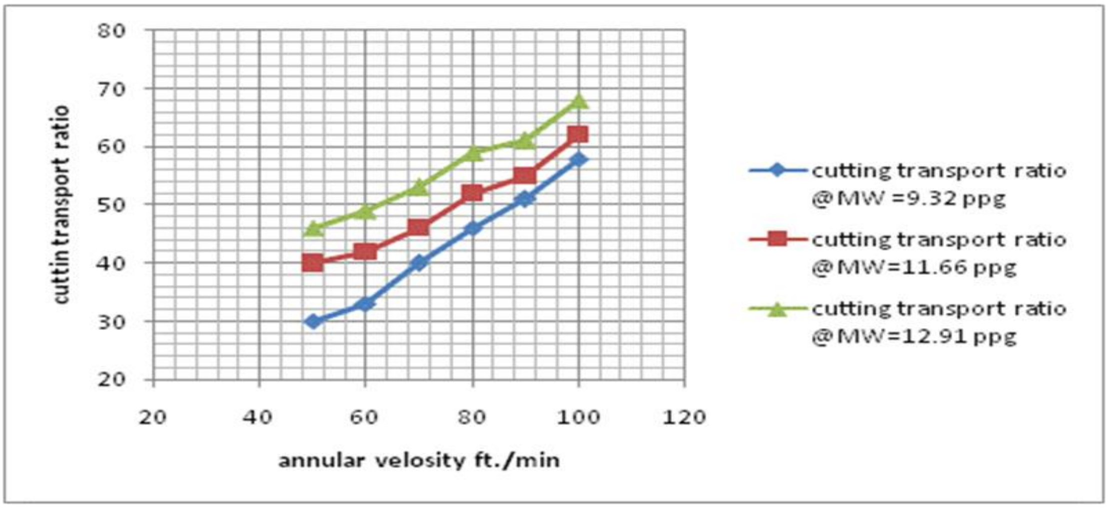

Fig. 2, the effect of mud type on cutting transport ratio

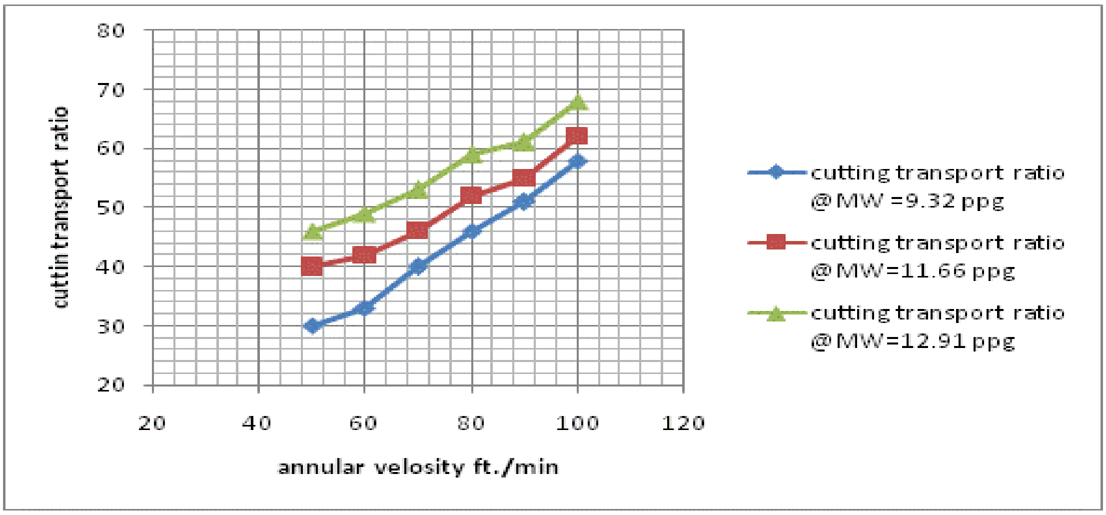

Fig. 3, The effect of mud weight on cutting transport ratio

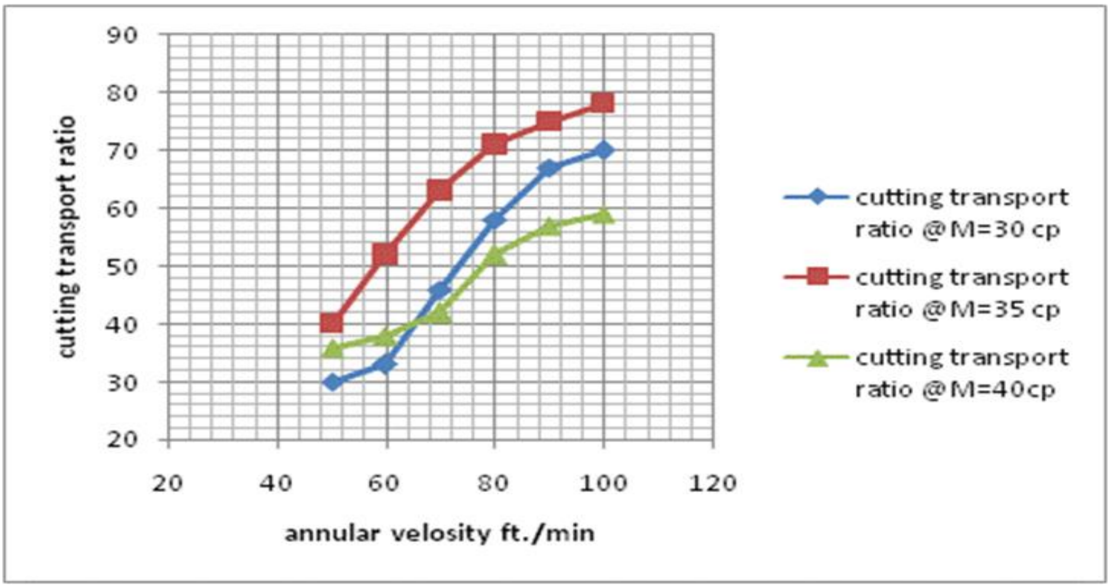

Fig. 4, the effect of mud viscosity on cutting transport ratio

Table 1, laboratory measurements for fresh bentonite mud

ϕ600	ϕ300	ϕ200	ϕ100	ϕ6	ϕ3
37	29	20	17	15	12
funnel vis.	52 sec/qt	mud weight	1.09 sp.gr	Pv	8 cp
gel 10 sec	12 lb./100ft^2	gel 10 min	18 lb./100ft^2	Yp	21 lb/100ft^2

Table 2, laboratory measurements for gel- bentonite mud

ϕ600	ϕ300	ϕ200	ϕ100	ϕ6	ϕ3
52	49	29	22	13	10
funnel vis.	57 sec/qt	mud weight	1.12 sp.gr	Pv	13 cp
gel 10 sec	10 lb./100ft^2	gel 10 min	15 lb./100ft^2	Yp	26 lb./100ft^2

Table 3, laboratory measurements for polymer mud

ϕ600	ϕ300	ϕ200	ϕ100	ϕ6	ϕ3
72	55	33	27	19	14
funnel vis.	61 sec/qt	mud weight	1.3 sp.gr	Pv	17 cp
gel 10 sec	15 lb./100ft^2	gel 10 min	25 lb./100ft^2	Yp	31 lb/100ft^2

Carrying Capacity Index (CCI)

Only three drilling parameters are controllable to enhance moving drilled solids from the well bore: annular velocity (AV), mud weight MW), and mud viscosity. Examining cuttings discarded from shale shakers in vertical and near-vertical wells during a 10-year period, it was learned that sharp edges on the cuttings resulted when the product of those three parameters was about 400,000 or higher. AV was measured in ft. /min, MW in lb. /gal, and viscosity (the consistency, K, in the Power Law model) in cp. When the product of these three parameters was around 200,000, the cuttings were well rounded, indicating grinding during the transport up the well bore. When the product of these parameters was 100,000 or less, the cuttings were small, almost grain sized. Thus, the term carrying capacity index (CCI) was created by dividing the product of these three parameters by 400,000: as shown in Eq. (1)

$$CCI = AV * MW * K/400000 \quad \ldots (1)$$

Robinson [9].

To ensure good hole cleaning, CCI should be 1 or greater. If the calculation shows that the CCI is too low for adequate cleaning, the equation can be rearranged (assuming CCI=1) to predict the change in consistency, K, required bringing most of the cuttings to the surface:

$$K = 400{,}000 / MW * AV \quad \ldots (2)$$

Since mud reports still describe the rheology of the drilling fluid in terms of the Bingham Plastic model, a method is needed to readily convert K into PV and YP. The chart given in Fig.5 serves well for this purpose. In a vertical hole, laminar flow with low PV and elevated YP or low n-value and high K-value (from the Power Law model) will produce a flat viscosity profile and efficiently carry cuttings out of the hole Walker [3].

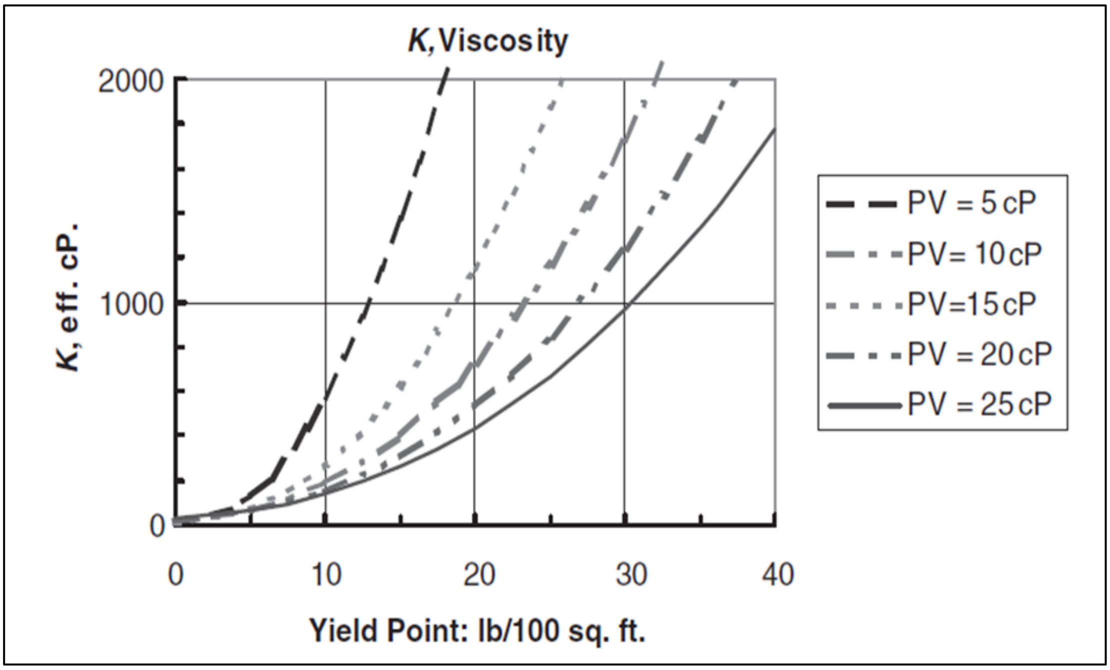

Fig. 5, conversion of bingham plastic yield point to power law. bourgoyne et all[18]

Experimental work

Three of mud samples have been studied in this study to find which of them can give good hole cleaning, those muds are: (bentonit and CMC), (X-anthan polymer), and oil base mud (direct emulsion) bellow the properties of each sample and the uses of each one:

1- CMC: Carboxymethyl cellulose is a cellulose derivative obtained by chemically modification the natural cellulose. CMC is one of the most important water soluble polymers with many advantages that other

natural or synthetic glues don't have. CMC is tasteless, smells, nontoxic nonflammable and easily dissolved in water to become transport, viscos solution Amoco[10]. CMC solution has good properties of thickening, adhering, emulsifying and stabilizing membrane forming .The solution of CMC can be mixed with dissolvable animal glues, glycerin, Arabic gum, and dissolvable starch. CMC can protect the shaft wall and prevent mud loss, thus enhance recovery efficiency; three type of CMC (LV-CMC, MV-CMC and HV-CMC) has the following characteristic:
-Excellent water retention even at low concentration and excellent rheological property.
-Excellent thickening effect and good resistance to salt mud and temperature change M-I llc [11]. The first mud consists from 4.2% of red bentonite and the HV.CMC additives begin from 03% to 2% and 450 cc of water.

2- X-anthan polymer: The natural polymers, which perform by thickening water, are essentially non-charged and are less sensitive to their environment. These materials increase the viscosity of water due to their molecular size, shape, and ability to absorb water. . Xanthan polymer is a viscosifier and affords very little fluid loss .X-anthan gum can build viscosity in fresh, sea and salt water without the assistance of other additives. Uniquely the molecular forms a rigid rod like structure in solution, this gives very high viscosity or gels at low shear rates. Consequently, xanthan polymer gives excellent suspension properties that cannot be matched by other polymers at equivalent. This polymer also Increase the carrying capacity of mud to enhance the hole cleaning API RP13D [12]. The second mud consists from 450 cc water and X-anthan gum begin from 0.2% to1.3%.

3- Oil base mud: oil base mud system is one in which the continuous phase of a drilling fluid is oil. When water is added as the discontinuous phase then it is called an invert emulsion. These fluids are particularly useful in drilling production zones, shales and other water sensitive formations, as clays don't hydrate or swell in oil. They are also useful in drilling high angle horizontal wells because of their superior lubricating properties and low friction when values between the steel and formation which result in reduced torque and drag API RP 13B2[13],. The third mud consist from 3.3% red bentonite and 450 cc of water and gas oil additives begin from 5% to 25% The rheological properties of the three studied drilling fluid is measured in the lab, By using viscometer Model 800 Viscometer to read the shear velocity to calculate the values of Pv and Yp by using Eq.3 and Eq.4 respectively:

$$Pv = {}^{\Phi}600 - {}^{\Phi}300 \qquad \dots (3)$$

$$Yp = 2 * {}^{\Phi}300 - {}^{\Phi}600 \qquad \dots (4)$$

The density of each drilling fluid is measured by using mud balance. By using the Carrying Capacity Index (CCI) equation to find which the drilling fluid that will give the value of CCI greater than 1, the experimental work and the results is shown in table (4), table (5) and table (6). The X-anthan gave good values of CCI comparing with the mixture of (bentonite and CMC) and oil base mud. The oil base mud gave the lowest value of CCI. It's clear that there is an increase in the YP/PV ratio in x-anthan mud and mixture of (bentonite and CMC), but for oil base mud there is decrease in the YP/PV ratio. The increase in the YP/PV ratio will generally flatten the flow profile and increase carrying capacity or Carrying Capacity Index while the decrease in YP/PV ratio lead to bad hole cleaning.

The values of Yb is low in oil base mud compared with x-anthan polymer and and mixture of (bentonite and CMC), also the values of k is low in oil base mud compared with x-anthan polymer and mixture (bentonite and CMC), also the density of oil base mud is low compared with x-anthan polymer and mixture (bentonite and CMC). All that parameters lead to decrease the value of CCI in oil base mud. The CCI is used in this research to choose the best drilling fluid from between the studied drilling fluids because its equation treat with the three drilling-fluid controllable parameters to enhance moving drilled solids from the well bore to lift it up. Those three drilling-fluid controllable parameters are: annular velocity (AV), mud weight MW), and mud viscosity. The annular velocity was 110 ft. /min.

Table 4, the experimental work and the results for mixture of (bentonite and CMC)

Bent. gm.	water cc	CMC gm.	ϕ600	ϕ300	Pv cp	Yb $lb/100ft^2$	yp/pv	K from fig. 5	CCI from eq.1
20	450	1.5	24	13	11	2	0.1818	65	0.1716
20	450	3	41	27	14	13	0.9286	200	0.528
20	450	4.5	49	33	16	17	1.0625	310	0.8184
20	450	6	58	41	17	24	1.4118	620	1.6368
20	450	7.5	67	48	19	29	1.5263	1010	2.6664
20	450	9	79	57	22	35	1.5909	1180	3.1152

Table 5, the experimental work and the results for x-anthan polymer

Water volum cc	x-anthan	ϕ600	ϕ300	Pv cp	Yb $lb/100ft^2$	yp/pv	K from fig 5	CCI from eq.1
450	1	12.5	7.5	5	2.5	0.5	42	0.100485
450	2	14	9	5	4	0.8	81	0.193793
450	3	24	18.5	5.5	13	2.3636	810	1.937925
450	4	53	38	15	23	1.5333	950	2.272875
450	5	75	51	24	27	1.125	988	2.36379
450	6	89	64	25	39	1.56	1550	3.708375

Table 6, the experimental work and the results for oil base mud

water cc	bent.gm	gas oil cc	gas oil by volume%	ϕ600	ϕ300	Pv cp	Yb lb/100ft^2	yp/pv	K from fig 5	CCI from eq.1	ρgas oil gm /cc
450	15	22.5	5	20	13	7	6	0.8571	90	0.2042	8.25
450	15	45	10	25	16	9	7	0.7778	110	0.245	8.1
450	15	67.59	15	28	17.5	10.5	7	0.6667	160	0.3432	7.8
450	15	90	20	44	26	18	8	0.4444	310	0.6539	7.67
450	15	112.5	25	51	31.5	19.5	12	0.6154	388	0.7992	7.49

Cutting Concentration Calculation in the Annulus in Vertical Hole

Sifferman published transport ratios collected with annular flow model made with a twelve inches outer steel diameter and various diameter inner tubes. The model was about 100 feet long. He defined transport ratio as in Eq. (4). His transport ratio is the seen to be the solid's velocity expressed as a fraction of the annular velocity.

$$T.R. = Vf - Vs/Vf \qquad \ldots (5)$$

Bourgoyne et al.[18].

Where: T.R. =transport ratio, Vf =mud annular velocity, fpm,Vs= solids free settling velocity, fpm

The annular fluid velocity is calculated by using eq. 6

$$Vf = 24.5 * Q/H2 - OD2 \qquad \ldots (6)$$

Bourgoyne et al [18]

Sifferman identified three types of mud for the publication of his transport ratios: thick, intermediate, and thin; and water has been added Sifferman[14]. The fan dial reading and gels of his muds are given in table (7). His chart was modified by sample gives transport ratios versus inverse mud annular velocity for his mud type and as shown in fig. (6).

Table 7, Sifferman mud types

Type	ϕ600	ϕ300	ϕ200	ϕ100	ϕ6	ϕ3	gel 10 sec	gel 10 min
thick	69	53	45	36	23	20	13	29
intermediate	49	35	30	25	15	13	13	22
thin	24	16	13	10	3	3	2	3

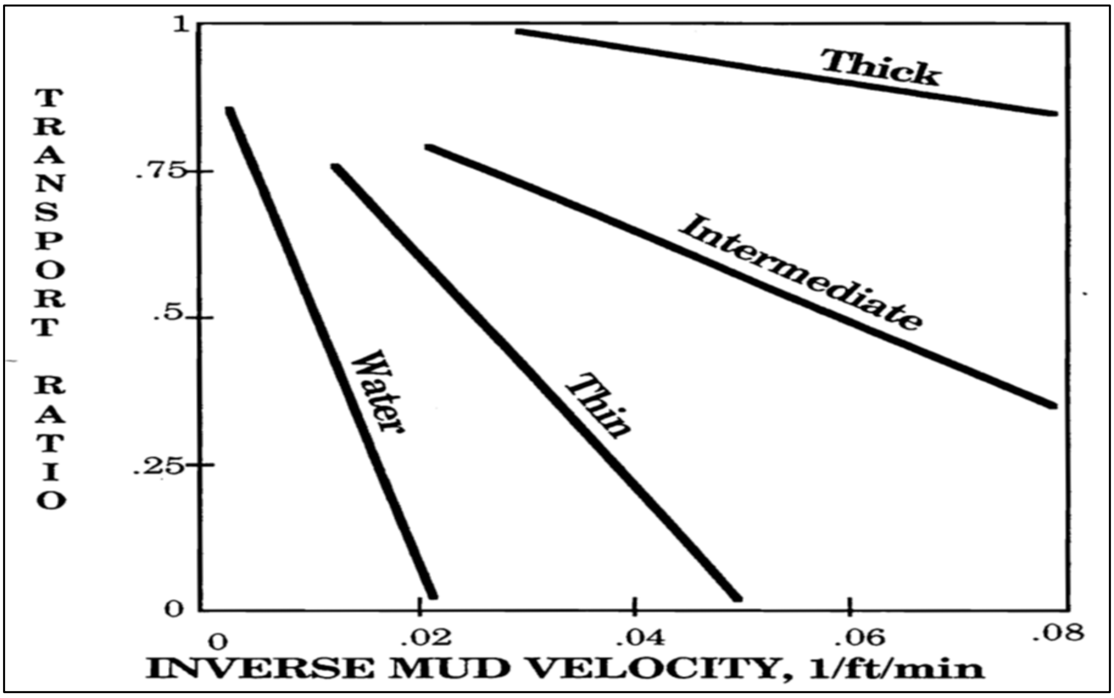

Fig. 6, Sifferman transport **Bourgoyne et al**

API used the following steady state equation for the volumetric drill cuttings in the annulus:

$$Vfc = ROP * Dbit/1471 * Q * T.R. \quad \dots (7)$$

Where:
ROP=average drilling rate, ft./hr.
Vfc=average new drill cutting concentration; vol%
Dbit =bit diameter; inch.
Q=circulating rate; gpm

Field Application

Field data from well in south of Iraq used to show the effect of mud viscosity on the cutting concentration, hole Size: 12.25″ hole, depth: (520 – 1568) m. By using Sifferman chart to find drill cutting transport ratio and API equation, Eq. (6) to find the volumetric drill cuttings in the annulus, the used mud type to drill the 12.25" hole section in this well was intermediate consistency, table 8 and table 9 show the properties of the used mud ,the fluid obey power law model. Table (7) shows the Sifferman mud types and table (8) shows laboratory measurement for the field mud, the fluid is obey yield –power low depending on the Average Absolute Percentage Error (AAPE) method. By comparing the values of shear rate for the field mud table (8) and in and the values of shear rate for the intermediate type in Table (7), the tow values are nearly the same values. So the field mud is considered to be intermediate consistency. Two cases of mud type also have been studied: the first case assumed that the drilling is done by using thick mud; the second case assumed that the drilling is done by using thin mud. The results showed that the used of thick mud increase the lifting capacity and decrease volumetric drill cuttings in the annulus but the using thin mud lead to decrease lifting capacity and increase volumetric drill cuttings in the annulus and as given in table (10). In fact the density and volume of cutting in the annulus cannot control it but the volumetric drill cuttings in the annulus can be under control. Beck[14].

Table 8, the laboratory measurement for the field mud

Φ_{600}	Φ_{300}	Φ_{200}	Φ_{100}	Φ_{6}	Φ_{3}
47	34	29	24	14	11
funnel vis.	55 sec/qt	mud weight	1.18 sp.gr	Pv	13
gel 10 sec	10 lb/100ft^2	gel 10 min	25 lb/100ft^2	Yp	21

Table 9, the materials that the drilling fluid consist from them

Additives	Function	Concentration lb./bbl.
Bentonite	To enhance viscosity, Gel, and Filter Cake	10 -15
Soda Ash	To Control pH & Total Hardness because of Ca++ ion & maintain pH between 9 – 10	0.5 – 1.0
Caustic Soda	To Control pH & Total Hardness because of Mg++ ion & maintain pH between 9 – 10	0.5 – 1.0
POLYSAL- HT	API Fluid Loss Controller	4 - 6
DUOVIS	Rheology	0.5 – 0.75
KCl - 3-5%	Weight material and Shale/Clay Inhibitor.	10 - 15
ASPHASOL SUPREME	Extra Inhibitor for Reactive Shale/Clay to avoid Tight Hole Condition & bit balling issue.	2 - 3
M-I PAC-UL	Fluid Loss control	0.5 - 2
Lime	Source for Alkalinity	0.5 -1
DRILZONE	Surfactant	0.5 - 0.7
CaCO3-F/Med	Weighting and bridging Agent	30

Table 10, the volumetric drill cuttings calculation in the annulus when Q=117 gpm

Vf fpm from Eq.5	1/Vf	lifting capacity from fig.6	Vfc (API) from eq.6	mud type	Dbit ,in	12.25
25.13	0.039	0.68	0.093	intermediate(real)	ROP,ft/hr	73
25.13	0.039	0.97	0.065	thick(assumed)	Q,gpm	117
25.13	0.039	0.29	0.22	thin (assumed)	ODdp	6

Table 11, the volumetric drill cuttings calculation in the annulus when Q=175gpm

Vf f/min from Eq.5	1/Vf	lifting capacity from fig.6	Vfc (API) from eq.6	mud ype	Dbit ,in	12.25
37.58	0.026	0.76	0.055	intermediet(real)	ROP,ft/hr	73
37.58	0.026	1	0.042	thick(assumed)	Q,gpm	175
37.58	0.026	0.52	0.081	thin (assumed)	ODdp	6

Table (12) shows the effect of the decreasing in the value of flow rate on the volume of cutting in the annulus and lifting capacity. In the case of using thin mud the value of the lifting capacity decrease to the half compared with original assumed value, and the volume of cutting in the annulus has increased to the forth compared with original assumed value, in other words the drilling with those conditions can be cause more problems. In the case of intermediate mud the value of lifting capacity also decrease from 68% to 57%,and. In the case of using thick mud, there is not difference between both lifting capacities values 97% and 91% because the high mud viscosity help to lift cutting out of the annulus until in the case of low value of flow rate.

Table 12, the volumetric drill cuttings calculation in the annulus when Q=88gpm

Vf from Eq.5	1/Vf	lifting capacity from fig.6	Vfc (API) from Eq.6	mud ype	Dbit ,in	12.25
18.68	0.053	0.57	0.15	intermediet(real)	ROP,ft/hr	73
18.68	0.053	0.91	0.09	thick(assumed)	Q,gpm	88
18.68	0.053	0.1	0.85	thin (assumed)	ODdp	6

Table (13) summarize the effect of flow rate values on the lifting capacity at different mud type

Table 13, the relation between flow rate (Q) and lifting capacity, (T.R.)

Q G/min	T.R. thin mud	T.R. intermediate mud	T.R. thick mud
88	0.1	0.57	0.91
117	0.29	0.68	0.97
175	0.52	0.76	1

Field Application Analysis

By using Eq. 7 and Eq.8 the values of slips velocities are calculated. The laminar mode shows the lowest slip velocity than turbulent mode so the flow pattern in the second interval assumed to be laminar flow. The value of lifting capacity of the second interval is better than the value of lifting capacity of the first interval and as shown in Fig. 7.

Cutting size is one of the parameters that influence the hole cleaning; in general large size cutting makes the hole cleaning more difficult. For the first interval the cutting size was 3.5" and for the second interval the cutting size was 2.5", that different in cutting size for both interval effects on lifting capacity. Based on the studied system ,at the first interval the fluid viscosity was 10 cp while for the second interval the fluid viscosity was 16 cp ,that increasing in the fluid viscosity enhancing the value of transport ratio and transform the flow pattern from turbulent to laminar. The fluid viscosity is increased by using HV

CMC. In other words the laminar flow gave good hole cleaning than turbulent flow for this well .The driller use more than one value of the density to get good value of lifting capacity, the fluid density is increased by using Barite. Those parameters it cannot be used in all oil wells (Is used in this well to show the effect of mud density on transport ratio) because of the hydrostatic pressure consideration. Also, the formation pressure for each drilled layer has effect on the value of the density, so it cannot be increase the value of density as we want.

Several investigators have proposed empirical correlations for estimating the cutting slip velocity like Moore and Chien correlation. The cutting transport efficiency in vertical wells is usually analyzed by computing the slip velocity, which is dependent on several factors such as: drilling fluid properties, operational parameters and particle property.Here we have two drilled intervals in well A, which have been drilled in south of Iraq, 12.25" hole section. At the first interval (446m to 1427m) the flow pattern was turbulent. Table (14) contains field data about the first intervals. The criteria that we are depended on to find the type of flow laminar or turbulent is alternate method, this method is as below:

1- Calculate the slip velocity for laminar mode by using Eq.8

$$\mathrm{VS} = 175 * \mathrm{Dp} * (\rho\mathrm{p} - \rho\mathrm{f})\ 0.667/\rho\mathrm{f}0.333 * Mf0.333 \quad \dots (8)$$

2- Calculate the slip velocity for turbulent mode by using Eq.8

$$\mathrm{VS} = 113.4 * [\mathrm{Dp} * (\rho\mathrm{p} - \rho\mathrm{f})/\ 1.5 * \rho\mathrm{f}]\ 0.5 \quad \dots (9)$$

3- Choose the lower value.

For the first interval which was from 446 m to 1427 m, the flow pattern was turbulent

By using Eq. 8 and Eq.9 the values of slips velocities are calculated. The turbulent mode shows the lowest slip velocity than laminar mode so the flow pattern in the first interval assumed to be turbulent flow. The second interval (1430 m to 2248m) the flow pattern was laminar.

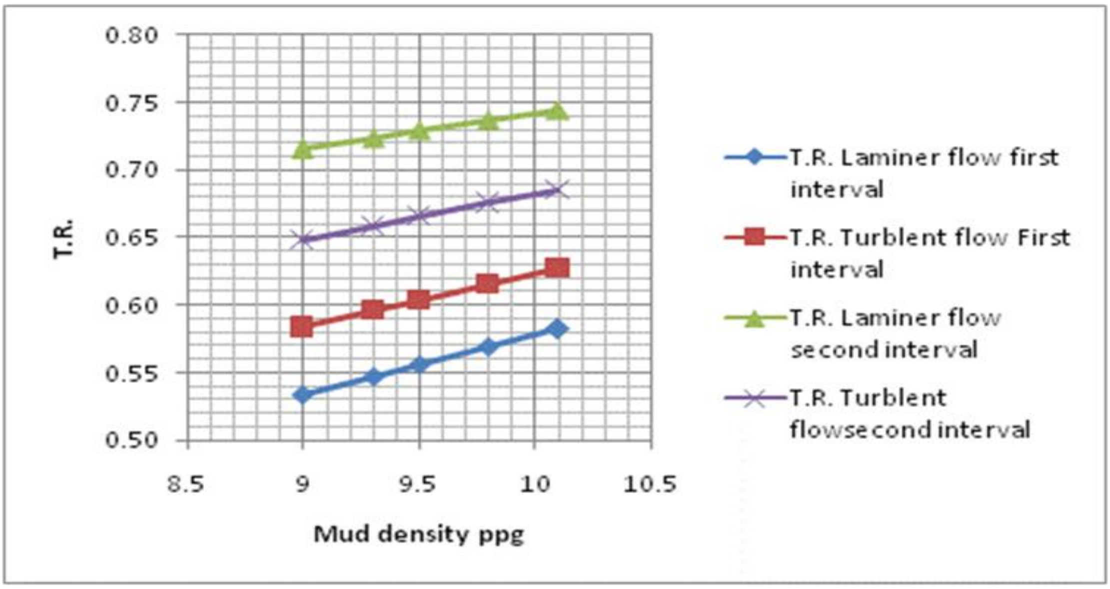

Fig.7, the relation between T.R. and Mud density for tow intervals in well A ,12.25" section

Table 14, the relation between T.R. and Mud density for the first oil well

Mud density ppg	Vs laminer ft./min	Vs turblent ft./min	T.R. Laminer	T.R. Turblent	Vm ft./min	145.5
9	67.76	60.56	0.53	0.58	Cutting density ppg	20
9.3	65.80	58.76	0.55	0.60	dp ,inch	5
9.5	64.51	57.59	0.56	0.60	Cutting size, inch	0.35
9.8	62.63	55.88	0.57	0.62	M_f cp	8-10)(
10.1	60.78	54.23	0.58	0.63	RPM,Rev./min	120

Table 15, the relation between T.R. and Mud density for the second oil interval

Mud density ppg	Vs laminer ft./min	Vs turblent ft./min	T.R. Laminer	T.R. Turblent	Vm ft./min	145.5
9	41.39	51.18	0.72	0.65	Cutting density, ppg	20
9.3	40.19	49.66	0.72	0.66	dp ,inch	5
9.5	39.41	48.67	0.73	0.67	Cutting size, inch	0.25
9.8	38.25	47.23	0.74	0.68	M_f, cp	14-16
10.1	37.12	45.83	0.74	0.68	RPM,Rev./min	120

The increasing in the annular velocity at known penetration rate is result from tow reason: the first one: the decreasing in the cutting concentration in the annuals lead to decreasing in the bottom hole pressure, the second one: As a result the friction in the flow system, the bottom hole pressure increase Rabia [17]. It can be get the annular velocity that will give the minimum bottom hole pressure, in other words, it can be reach to the best hole cleaning at the minimum bottom hole pressure ,therefore the annular velocity at minimum bottom hole pressure is known as optimum annular velocity. Eq.10 is used to calculate the pressure gradient (bottom hole pressure (psi)/depth (ft)) for laminar flow. Eq.11 is used to calculate the pressure gradient (bottom hole pressure (psi)/depth (ft)) for turbulent flow Burgoyne [18]. Fig 9. and table(16) clarify the relationship between annular velocity and bottom hole pressure.

$$\mathrm{Pwm/D} = \rho\mathrm{m}/19.2 + \mathrm{ROP}\ (\rho\,\mathrm{c} - \rho\mathrm{m})/19.2 * (1 - (\mathrm{dh} - \mathrm{dp}) * (\mathrm{Vm} - \mathrm{KVs}) + \mathrm{K} * \tau/225 * -(\mathrm{dh} - \mathrm{dp}) + \mathrm{k} * \mu p * vm\ /90{,}000(\mathrm{dh} - \mathrm{dp})\ 2 \quad \ldots (10)$$

$$\mathrm{Pwm/D} = \rho\mathrm{m}/19.2 + \mathrm{ROP}\ (\rho\,\mathrm{c} - \rho\mathrm{m})/19.2 * (1 - (\mathrm{dp/dh})2) * (\mathrm{Vm} - \mathrm{KVs}) + \mathrm{k} * \rho m * vm2 * F\ /92{,}900(\mathrm{dh} - \mathrm{dp}) \quad \ldots (11)$$

Where:

$P_{wm:}$ bottom hole pressure psi, D:hole depth ft , $\rho_{m:}$mud density ppg , ρ_{c}: cutting density ppg , τ:shear stress , $d_{h:}$ hole diameter in , $d_{p:}$ pipe diameter in, μ_p: plastic viscosity cp, F:friction factor, K: velocity correction factor.

When the mud velocity in the annular is greater than the optimum mud velocity, the bottom hole pressure increase as the annular velocity increase. When annular velocity is greater than critical velocity the flow pattern is transform from laminar to turbulent and as shown fig 9. and table14. The optimum annular velocity is at minimum bottom hole pressure therefore; graphically from fig.9 it can be found it, it is about 94 ft/min.

Note: the data in in table 16 represent field data for well in south of Iraq, mud density= 9.6-10-2)ppg , ρ_c=22 ppg, d_h =12.25" , $d_{p=}$ 8" .The data in table 16 is gotten by flowing gradient survey /slick line tools , Is a device used to assess the well pressure and temperature while flowing from bottom to the up by quartz gages.

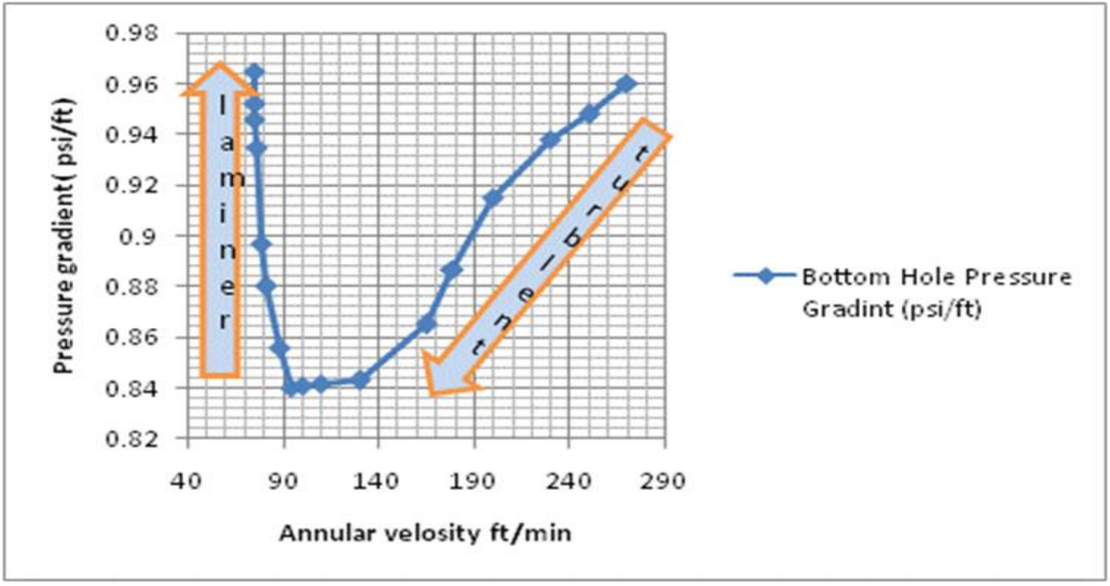

Fig .9, the relationship between annular velocity and bottom hole pressure.

Table 16, The relationship between annular velocity and bottom hole pressure

annular velocity ft./min	bottom hole pressure /depth psi/ft.	flow type
75	0.965	laminar
75	0.952	laminar
75	0.946	laminar
76	0.935	laminar
79	0.897	laminar
81	0.88	laminar
88	0.856	laminar
94$(V_m)_{Optimum}$	0.84 minimum bottom press.	optimum annular velocity
100	0.841	turbulent
110	0.842	turbulent
130	0.843	turbulent
165	0.865	turbulent
179	0.887	turbulent
200	0.915	turbulent
230	0.938	turbulent
250	0.948	turbulent
270	0.96	turbulent

Another way to increase AV is to reduce the planned size of the annulus by using larger-OD drill pipe. Not only does a larger pipe generate a smaller annular gap, thereby increasing fluid velocity, it also increases the effect of pipe rotation on hole cleaning. Although reducing the annular gap can greatly improve hole cleaning, it also makes fishing more difficult.

Table 17, field data

ODp ,in	Va ft./min	Other assumed data
6	257.75	Dh ,in
6.5	272.70	12.25
7	290.91	Q,gpm
7.5	313.39	1200
8	341.61	-

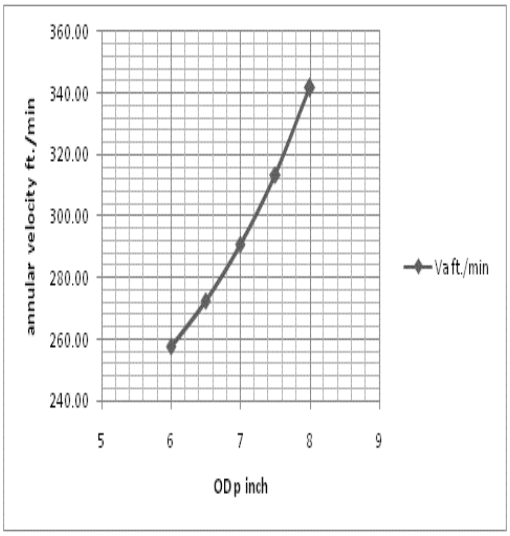

Fig. 10

Conclusions

1- The results show that the slip velocity is decrease when the cutting size is decrease, that decreasing in the value of slip velocity lead to enhance the value of transport ratio.

2- The results show that the annular velocity increases as the ODp increases, that increase in the value of annular velocity lead to good hole cleaning.

3- The experimental work show that the X-anthan polymer gave good values of CCI comparing with the mixture of (bentonite and CMC) and oil base mud.

4- From field application is found that the mud type and the flow rate have great effect on the value of cutting concentration in the annulus and lifting capacity.

5- In a vertical hole, laminar flow with low PV and elevated YP or low n-value and high K-value (from the Power Law model) will produce a flat viscosity profile and efficiently carry cuttings out of the hole.

6- The viscosity is related with hole cleaning, and it has major effect on the value of lifting capacity than density, in other words moderate value of viscosity with high value of RPM give good hole cleaning.

Nomenclatures

BHA: bottom hole assembly.
ROP: rate of penetration, ft. /sec.
RPM: revolution per minute, Rev. /min.
CCI: Carrying Capacity Index
CMC: Carboxymethyl cellulose
P_{wm}: Bottom hole pressure.psi
T.R. : Transport Ratio.
AV: Annular Velocity,fpm.
AAPE: Average Absolute Percentage Error

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